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THESIS

A METHODOLOGICAL APPROACH FOR CONDUCTING A BUSINESS CASE ANALYSIS (BCA) OF ZEPHYR JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)

by

Yew Heng, Kwok

December 2008

Thesis Advisor:	Daniel Nussbaum
Second Reader:	Alex Bordetsky

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13. ABSTRACT (maximum 200 words)

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The objective of this study is to analyze the Return on Investment (ROI) of the Zephyr system. This is achieved by (1) Developing a model to carry out Business Case Analysis (BCA) of JCTDs, including defining the methodical structure required in the business case report. (2) Conducting Zephyr JCTD BCA, with a baseline analysis, followed by sensitivity, as well as a quality risk assessment for the Zephyr system.

The BCA compares the life cycle costing with Global Observer, a liquid-hydrogen fuelled UAV, in operational scenarios over a period of 15 years.

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A METHODOLOGICAL APPROACH FOR CONDUCTING A BUSINESS CASE ANALYSIS OF ZEPHYR JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)

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Zephyr, a high altitude long endurance (HALE) solar powered, unmanned aerial vehicle (UAV) is thus identified as a Joint Capability Technology Demonstration (JCTD) candidate. This program is managed by the Office of Secretary of Defense (OSD) and is sponsored by United States Central Command (USCENTCOM) and United States European Command USEUCOM. This program aims to accelerate the development and operational evaluation of the Zephyr concept so that the system can transit to production and be deployed in the field to address military needs in the quickest possible time.

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EXECUTIVE SUMMARY

Zephyr, a high altitude long endurance (HALE) solar powered, unmanned aerial vehicle (UAV) is thus identified as a Joint Capability Technology Demonstration (JCTD) candidate. This program is managed by the Office of Secretary of Defense (OSD) and is sponsored by United States Central Command (USCENTCOM) and United States European Command (USEUCOM). This program aims to accelerate the development and operational evaluation of the Zephyr concept so that the system can transit to production and be deployed in the field to address military needs in the quickest possible time.

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The BCA compares the life cycle costing with the Global Observer, a liquid-hydrogen fuelled UAV, in operational scenarios over a period of 15 years; the results of the analyses are as follows:

- The total Life Cycle Cost Estimates (LCCE) savings for acquiring and operating Zephyr over Global Observer over a 15 year period is estimated to be $794M (FY08$), starting from FY 08.
    - The investment savings is $405M (FY08$) or approximately 91% of the investment cost for Global Observer.
    - The operating and support savings is $389M (FY08$) or approximately 77% of the operating and support cost for Global Observer.
- There is also an estimated potential cost avoidance of $41.8M (FY08$) per annum on commercial satellite bandwidth usage in that Zephyr can be

deployed to provide tactical battlefield communications over the area of interest, an addition to its ISR mission.

- The base case annualized compounded ROI over a 15-year period from FY08 is 22% based on a NPV saving of $793,497K (FY08$).
- The base case annualized ROI decreases to about 16% when Zephyr aircraft AUC increases from 1.8M to 3.5M (FY08$), almost doubling the estimated aircraft AUC used in the base case analysis.
- The base case annualized ROI does change significantly when the CGS cost or the payload is varied from 5% to 20% of the aircraft AUC. The ROI remains at approximately 22% to 23%.
- The number of Zephyr systems that can be purchased given the funds required to purchase one unit of Global Observer system is ten, at a cost of $2,200K (FY08$). This increases to 37 when the unit cost of the Zephyr system is reduced to $600K (FY08$) for a 15-year period starting from FY08.
- The number of Zephyr systems that can be purchased and supported given the funds required to purchase and support one unit of Global Observer system is six, at a cost of $154,404K (FY08$) for a 15-year period starting from FY08.
- The number of Zephyr systems that can be acquired and supported given the funds required to acquire and support one unit of the Global Observer system ranges from four to ten when the aircraft AUC decreases from $1.8M (FY08$) to $0.6M (FY08$), with a discount rate increasing from 0% to 20%.
- The number of Zephyr systems that can be acquired and supported given the funds required to acquire and support one unit of the Global Observer system remains from four to ten when the aircraft AUC decreases from $1.8M (FY08$) to $0.6M (FY08$), with a discount rate increasing from 0% to 20% and a GCS or payload cost varies from 5% to 20% of the Zephyr aircraft AUC.

- The number of Zephyr systems that can be acquired and supported given the fund required to acquire and support one unit of the Global Observer system ranges from four to eight when the annual O&S cost decreases from \$7.7M (FY08\$) to \$4M (FY08\$) with a discount rate increasing from 0% to 20%.
- The reliability of the Zephyr system remains uncertain even though there are claims of success in its flight demonstrations.

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I. INTRODUCTION

A. PURPOSE OF THE STUDY

In modern military operations, the need for continual communication, command, and control (C3) and persistent intelligence, surveillance and reconnaissance (ISR) are critical for mission success, especially when ground forces are deployed deep in inhospitable geographical terrains, where C3 and ISR are a challenge to maintain. Several options are available to tackle this problem but they have proved to be economically unfeasible. USCENTCOM and USEUCOM have recognized that there is a need for cost effective C3 and ISR capabilities to sustain these military operations.

Zephyr, a high altitude long endurance (HALE), solar powered, unmanned aerial vehicle (UAV) has been identified as a Joint Capability Technology Demonstration (JCTD) candidate. This program is managed by the Office of Secretary of Defense (OSD) and is sponsored by USCENTCOM and USEUCOM. This program aims to accelerate the development and operational evaluation of the Zephyr concept, so that the system can transit to production and be deployed in the field to address the military's needs in the quickest possible time.

The objective of this study is to analyze the Return on Investment (ROI) of Zephyr system. This is achieved by

- developing a model to carry out Business Case Analysis (BCA) of JCTDs, including defining the methodical structure required in the business case report.
- conducting Zephyr JCTD BCA, with a baseline analysis, followed by sensitivity, as well as a quality risk assessment for the Zephyr system.

The BCA compares the life cycle costing with the Global Observer, a liquid-hydrogen fuelled UAV, in operational scenarios over a period of 15 years.

B. WHAT ARE INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE AND COMMAND, CONTROL AND COMMUNICATION?

The Department of Defense (DoD) defines intelligence as "information and knowledge obtained through observation, investigation, analysis, or understanding." [1] Surveillance and reconnaissance refer to "the means [by] which the information is observed, with surveillance being a systematic observation to collect whatever data that is available, while reconnaissance is a specific mission performance to obtain specific data." [2] For this thesis, intelligence, surveillance and reconnaissance will be used collectively to mean everything from observation to collection of data.

In the modern military era, ISR plays a critical role during wartime or peacetime. It helps commanders to know and to understand both the situation and the enemy so that they can plan an appropriate course of action to ensure mission success. As Sun Tze, an ancient Chinese warrior, wrote, "If you know your enemy and yourself, in hundred battles you will never peril." The effectiveness of ISR also greatly depends on its ability stay on-station for an extended period of time, or persistence ISR. If the ISR is able to continuously capture and feed back to the commander all the data it captures, then useful and accurate information can be inferred from these data.

Command, control, and communication refer to the ability of commanders to instruct and direct the ground forces by means of effective interaction with them. This is typically done using commercial communications satellite bandwidth. This bandwidth acts like a "highway" to transmit text data such as email, voice data and image data. If the bandwidth is high, then more data is able to flow through the "highway" at a rapid rate, which will result in the continuous flow of data to and from a commander. If the commander is video conferencing with his ground forces, this would require good picture and voice quality without any distortion or lags. Commanders always want high bandwidth for their C3 operations but very often are limited to a certain amount of bandwidth. One main reason is because of the high cost incurred in obtaining the bandwidth, which makes it economically unfeasible to do so for a long period of time.

C. SOLAR POWERED UNMANNED AERIAL VEHICLE

Solar power generally refers to the conversion of sunlight into electricity. Everyday the sun sends out an enormous amount of energy, of which only a small percentage reaches the earth, about 1 part in 2 billion [3]. Nevertheless, this small amount of energy is sufficent to supply the United States of America's energy needs for one and a half years.

The conversion of solar energy to electrical energy is carried out using photovoltaic (PV) cells. These PV cells are made of semiconductor materials, such as silicon which display photoelectric characteristics when sunlight strikes them, and produces electricity. In some cases, an array of PV cells is used to generate electricity which is sometimes stored in rechargable batteries and which is then used when there is insufficient light or a complete absence of sunlight (e.g. night time) to generate electricity for practical uses. This cycle of storing and using electrcity via rechargeable batteries ensures a continuous supply of electricity, regardless of day or night time.

The range of possible applications of solar energy using PV cells is vast, from powering a simple calculator to powering a complex vehicle system. Over recent decades, this technology has also been integrated into UAVs, so that the flight endurance of UAVs is no longer dependent on the quantity of fuel that they can carry onboard, thus increasing their flight endurance significantly. Table 1 shows the different solar powered UAV systems and their developmental status in 2008/ 2009. Almost all systems are still in the "proof of concept/continuing development" stage, which suggests that this technology is still in its infancy as regards the UAV industry; serious efforts are still on-going to ensure that the concept is fundamentally sound in its application to UAVs.

Table 1. Solar Powered UAVs and Their Development Status [From 4]

Producer	Country	System	Status
Tecknisolar-Seni	France	D.E.R.E	Proof of Concept/ Development Continuing
Tecknisolar-Seni	France	Libellule	Proof of Concept/ Development Continuing
Alcatel, Belgium&vito, Belgium & Verhaert, Belgium and QinetiQ, UK	International	Pregasus	Proof of Concept/ Development Continuing
Politecnico Tori& Euro Consortium	International	Heliplat	Proof of Concept/ Development Continuing
IAI-Malat&Technion University	Israel	Sun Sailor	Proof of Concept
QinetiQ – Farnborough	UK	Mercator	Ordered as test/ demonstration system
AC Propulsion	USA	So Long	Proof of Concept/ Development Continuing
AurAaYan Aerospace	USA	AeroLens Craft	Development Continuing
Lockheed Martin	USA	High Altitude Airship	Proof of Concept/ Development Continuing
DARPA	USA	Vulture	Feasibility Study
AeroVironment	USA	Pathfinder Plus	No longer in development

D. PROBLEM STATEMENTS

As modern warfare becomes more sophisticated, the need to enhance current fighting capabilities is highly desirable so as to ensure a winning advantage over the enemy. USCENTCOM and USEUCOM have thus identified a need for "rapid, secure over-the-horizon command, control and communications and intelligence, surveillance and recconaissance capabilities" [5]. Moreover, the deployment of current C3 and ISR capabilities is also hindered by its high cost in procurement, as well as its operation and support.

1. High Cost in Global Persistent Surveillance

Over decades, the outcomes of UAV developmental programs have not met expectations. Technical problems such as the inability to integrate sensors, platforms, and ground elements have caused project schedules to overrun and inevitably push unit production costs to a level far in excess of what U.S. DoD are willing to pay. In an article in *Defense Industry Daily* [6], it was reported that a $143 million contract was awarded to Northrop Grumman Systems Corporation to provide for contract price increases and funding to account for the long-range Global Hawk UAV's Engineering and Manufacturing Development overruns. This cost overrun was due to design modifications in the airframe and wings, and directly caused the unit price of Global Hawk to increase to $35 million.

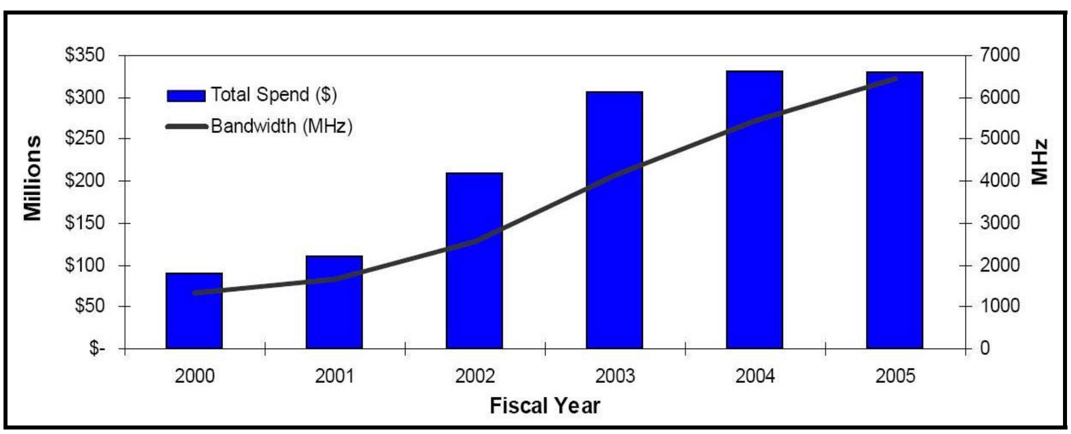
However, the increase of cost is not the only contributor to high costs in global persistence surveillance. The nature of an operation can also add to its cost. In most missions today, the need for 24/7/365 surveillance is essential for almost all operations. Because UAVs are not able to fly for long periods of time, numerous sorties are required to sustain a continuous surveillance operation. This would add to operation and support (O&S) costs, which could eventually make a surveillance operation too expensive to carry out.

2. High Cost and Shortage of Communications Bandwidth

A robust and uninterrupted communication network between commanders and ground forces, as well as between ground forces, is vital in all military operations. This ensures that information shared is not ambiguous and that commanders are able to improve their situational awareness and make decisive commands instantly.

Currently, the US DoD leases commercial satellites to provide the necessary bandwidth for communications during military operations, but in recent years demand for communications bandwidth has increased exponentially. It is estimated that the bandwidth used during 2002's Operation Enduring Freedom, in Afghanistan, was seven times greater than the bandwidth used in the 1991 Gulf War; Operation Iraqi Freedom, in 2003, is estimated to have required bandwidth roughly ten times that of the 1991 Gulf War [7]. This increase has resulted in a significant increase in DoD expenditure on leased commercial satellite bandwidth. In 2000, the DoD spent $91 million for 1,324 Mhz of bandwidth leased; in 2005, the amount spent increased to $330 million for 6,444 Mhz leased. Figure 1 shows the shows the growth in commercial satellite expenditures and bandwidth usage from 2000 to 2005:

Figure 1. Growth in Commercial Satellite Communications Expenditure and Bandwidth Usage [From 8, Fig 2-1]



E. CASE FOR CHANGE — DOING THINGS BETTER

In order to sustain war superiority against the enemy, the need for ISR and C3 capabilities is essential. However the implementation of the current ISR and C3 capabilities is too costly to support the battle adequately and, thus, the need to find a cost effective solution is vital.

Joint Capability Technology Demonstrations (JCTD) is a program managed by the Office of Secretary of Defense (OSD). Its aim is to accelerate the development and operational evaluation of potential technologies that are able to address military needs, so that the technologies can transit to production and be deployed in the field in the quickest possible time.

Hence the Zephyr system has been identified as one of the JCTD candidates, which aims to alleviate the high cost of persistent surveillance and communications, as well as to solve the problem of the shortage of communications bandwidth.

D. RESEARCH METHODOLOGY, LIMITATIONS AND ASSUMPTIONS

To achieve the objectives set out in Section A, the author will

- develop and recommend an analytic structure for performing business case analyses (BCA)
- conduct a BCA for Zephyr JCTD based on this structure
- report on the results of Zephyr JCTD BCA
- formulate the appropriate recommendations to the decision makers.

The degree of comprehensiveness to which this thesis presents the BCA is limited to the data and information made available to the author. Key assumptions made while performing the BCA are as follows:

- A conservative approach is adopted, i.e., whenever a choice had to made between higher and lower costs due to ambiguity in the data, the higher cost is used.

- Where information is not available, or was not made available to the author, estimates are used and reasonable assumptions are made in regards as to how they are derived.

II. BACKGROUND

This section provides an overview of the key technologies currently employed for global surveillance and communications missions. It also includes new technologies that are being developed in order to alleviate the high cost of global persistent surveillance, as well as to address the problem of the existing shortage of bandwidth resources. A summary of the Joint Capability Technology Demonstration (JCTD) Program is also explained, with details on the history and development of the Global Observer JCTD Program. Finally, the section concludes with an overview of the Business Case Analysis (BCA) methodology.

A. CURRENT TECHNOLOGIES

Lim [9] identified 3 main types of technologies that are being deployed, or are being developed, for surveillance and communications missions. The three main types are as follows:

- fossil-fueled UAVs (flexible deployment, but limited loiter capability)
- satellites (inflexible deployment, but persistent loiter capability)
- High Altitude Airships (relatively flexible deployment, with persistent loiter capability)

1. Fossil-fueled UAVs

UAVs are remotely piloted or self-piloted aircraft that can carry cameras, sensors, communications equipment, or other payloads that are able to provide ISR and C3 capabilities to support combat missions. UAVs are classified into several categories, and these are summarized in Table 2:

Table 2. UAV Classifications [From 4]

Categories, (Acroym)	Range (km)	Flight Altitude (m)	Endurance (hours)	MTOW (kg)
Nano, (□)	< 1	100	< 1	< 0.025
Micro, (μ)	< 10	250	1	< 5
Mini, (Mini)	< 10	150 – 300	< 2	< 30
Close Range, (CR)	10 – 30	3,000	2 – 4	150
Short Range, (SR)	30 – 70	3,000	3 – 6	200
Medium Range, (MR)	70 – 200	5,000	6 – 10	1,250
Medium Range Endurance, (MRE)	> 500	8,000	10 – 18	1,250
Low Altitude Deep Penetration, (LADP)	> 250	50 – 9,000	0.5 – 1	350
Low Altitude Long Endurance, (LALE)	> 500	3,000	> 24	< 30
Medium Altitude Long Endurance, (MALE)	> 500	14,000	24 – 48	1,500
High Altitude Long Endurance, (HALE)	> 2000	20,000	24 – 48	4,500
Unmanned Combat Aerial Vehicle, (UCAV)	Approx. 1500	10,000	Approx. 2	10,000
Lethal, (LETH)	300	4,000	3 – 4	250
Decoy, (DEC)	0 – 500	5,000	< 4	250
Stratospheric, (STRATO)	> 2000	>20,000 & <30,000	> 4	TBD

The main advantage of deploying UAVs is that they can fulfill the role of manned aircraft to carry out missions that are considered “dull,” “dirty,” or “dangerous.” This not only saves valuable human resources for other critical missions, but it also eliminates the risk of losing human lives during missions.

However, these missions are limited by the flight endurance of UAVs. Flight endurance is highly dependent on the amount of fuel that a UAV can carry. The more fuel an aircraft is able to carry, the longer its flight endurance, and as a result, the greater its ability to stay on-station. However, no UAV has a maximum flight endurance of greater than 48 hours, regardless of the amount of fuel any given it carries; in order to sustain a

mission that requires 24/7/365 coverage, numerous aircraft and sorties are required. Hence, the cost of deploying a fossil-fueled UAV for 24/7/365 missions is significant.

2. Satellites

A satellite is a man-made spacecraft placed into orbit around the earth, and that carries electronic devices which transmit signals to Earth and receive signals in return. The first satellite, Sputnik 1, was launched on 4 October 1957 by the Soviet Union, which ushered in an era of new political, military, technological, and scientific development. Its launch also marked the start of the space age and the U.S. – U.S.S.R. "space race" [10]. The space race soon spilled over to other countries and over the last three decades, the Ukraine, Japan, China, India, and Israel have successfully launched satellites into orbit on their own nationally-developed launch vehicles [11]. Many other countries are also actively pursuing and developing this area of interest.

There are many uses for satellite technology that include both military and non-military applications. The main military uses of satellite technology are for communications and ISR purposes. The advantage of using this technology is that it can provide 24/7/365 on-station capability for any mission, without concerns about the enemy's ability to detect and shoot down the satellite. However, there is a downside to using this technology. The cost of launching a satellite into space is estimated to range from $50 million to $400 million per launch. Moreover, satellites, once launched, are non-recoverable and mission specific; that is, they cannot be retrieved and re-configured to carry out other missions. For example, if a mission requires an ISR capability, the satellite will be designed as a spy satellite, with an imagery payload mounted, and launched into space. In an event that communications capability is required, the satellite cannot be recovered and re-configured to be a communications satellite. Rather, there will be a need to launch a communications satellite for this purpose; as a result, the costs of employing both ISR and communications capabilities using satellites technology are considerable.

3. High Altitude Airships

A high altitude airship is an unmanned, lighter-than-air vehicle that operates above the jet stream in a geostationary position; it delivers persistent station keeping as surveillance platform, telecommunications relay, or weather observer [12]. It is envisioned that this technology will provide a less costly alternative to address gaps in ISR and communications applications for the military and commercial world.

This technology is still in the developmental stage, but investors are optimistic about its future. The current forerunner developments in this field are:

a. The Composite Hull High Altitude Powered Platform (CHHAPP) [13]

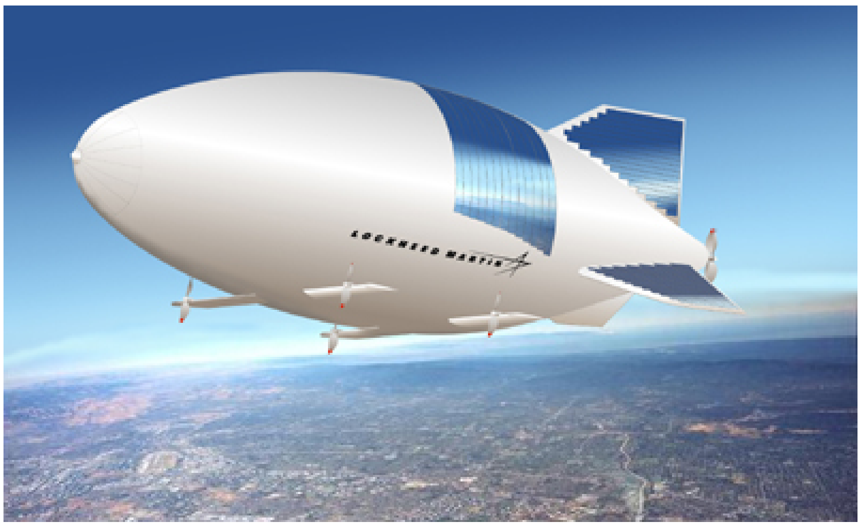
CHHAPP is an effort of the United States Army and Missile Defense Command program to demonstrate a powered stratospheric airship at high altitude and for a long endurance period. The first airship developed under this program was the Aerostar International Hisentinel, which was tested in 2005. It reached an altitude of 74,000 feet and carried a payload of 27 kilograms. The long-term objective for CHHAPP is to carry a payload of up to 440 kilograms for as long as a month. The CHHAPP is shown in Figure 2.

Figure 2. Composite Hull High Altitude Powered Platform (CHHAPP) [From 14]

b. *High Altitude Airship*

The High Altitude Airship (HAA) is being developed by Lockheed Martin and is sponsored by the US Army Space and Missile Defense Command (USASMDC). The production HAA are expected to flown at a height of 65,000 feet or up to six months at a time, carrying a 1800-kilogram radar [12]. The first flight is expected to take off in 2010. The HAA is shown in Figure 3.

Figure 3. Lockheed Martin's High Altitude Airship (HAA) [From 15]

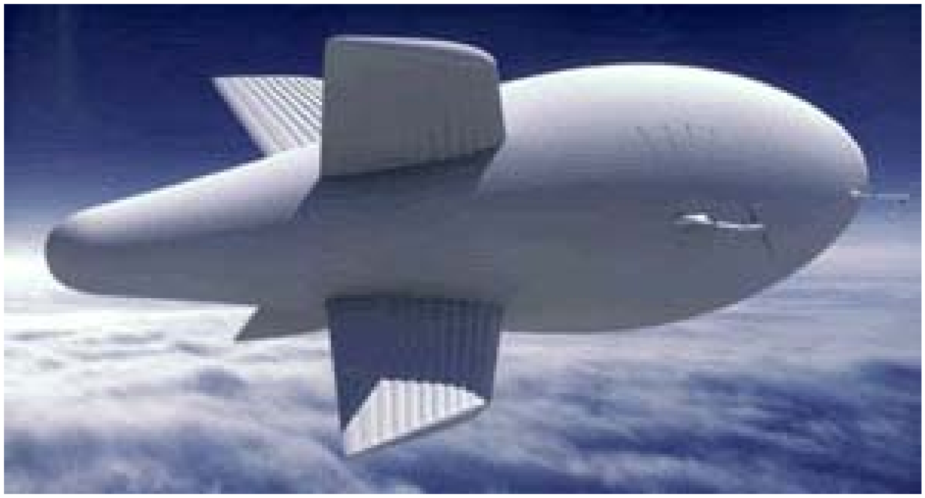


c. *Integrated Sensor Is Structure (ISIS)*

The ISIS is being developed jointly by Northrop Grumman and Lockheed Martin and is sponsored by the Defense Advanced Research Projects Agency (DARPA). The program aims to develop a stratospheric airship-based autonomous unmanned sensor with years of persistence in the surveillance and tracking of air and ground targets [16]. This program is different from the other high altitude airship programs in the sense that this program focuses on the payload rather than the airship platform. The payload aboard ISIS accounts for roughly 30 to 40 percent of its platform weight, whereas the payload aboard other airship concepts is significantly smaller. The ISIS airship is shown in

Figure 4. However, with the as-yet uncompleted development and testing of these capabilities, any possible operational deployment would still be some years away.

Figure 4. DARPA's ISIS Airship [From 17]



B. JOINT CAPABILITY TECHNOLOGY DEMONSTRATION (JCTD)

The JCTD program evolved from the Advanced Concept Technology Demonstration (ACTD) Program, which had its inception in 1994 under the sponsorship of the Department of Defense (DoD). The program is led by the Deputy Under Secretary of Defense (Advanced Systems and Concepts), DUSD (AS&C), who works with a team of ACTD/JCTD oversight executives to interact with the various AS&C divisions to harvest capabilities for Combatant Commands.

1. The ACTD Program

The objective of the ACTD program is to help DoD acquisition processes adapt to present-day economic and threat environments by exploiting mature, advanced technologies to develop solutions for critical military problems. Each ACTD program focuses specifically on one or more war fighting needs and is carefully reviewed by the Services, Defense Agencies and Joint Staff for its suitability. Potential solutions are then proposed for initiation in each fiscal year and those with the greatest prospective are

submitted to the Joint Staff/Joint Requirement Oversight Council (JROC) for prioritization.

ACTDs are characterized by their employment of mature technologies over a fixed period of activity. In addition, they leverage existing technological investments. Finally, ACTDs have a strong focus on joint operations with Combatant Command warfighter participation, as well as a significant level of cross-service, cross-agency/organization involvement.

The guidelines [18] developed for the selection of ACTD candidates are:

- The timeframe for completing the evaluation of military utility is typically 2–4 years.
- The technology should be sufficiently mature.
- The project provides a potentially effective response to a priority military need.
- A lead service or agency has been designated.
- The risks have been identified, understood, and accepted.
- Demonstrations or exercises have been identified that will provide an adequate basis for utility assessment.
- Funding is sufficient to complete the planned assessment of utility and to provide technical support for the first two years of fielding the interim capability.
- The developer is ready to prepare a plan that covers all essential aspects. These include affordability, interoperability, sustainability, and evolutionary capability, vis-à-vis technology and threat changes.

The objectives of the ACTD are to conduct meaningful demonstrations of the capability, to develop and test concepts of operations to optimize military effectiveness, and to prepare to transition the capability into acquisition without loss of momentum, if warranted. An additional goal of the ACTD is to provide a residual capability to further refine CONOPS and to permit continued use prior to formal acquisition, as well as to provide the ability to proceed into formal acquisition for additional capability, if required.

Possible outcomes after the ACTD operational demonstration are:

- The user sponsor may recommend the acquisition of the technology and field the residual capability that remains at the completion of the demonstration phase of the ACTD to provide an interim and limited operational capability;
- The user's need is fully satisfied by the residual capability remaining at the conclusion of the ACTD, and there is no requirement to acquire any additional units of the system;
- The capability is deemed to not demonstrate sufficient military utility, resulting in the project being terminated or returned to the technology base.

2. The JCTD Program

In FY2006, a new ACTD business process was initiated to update the successful ACTD program to meet the DoD's transformational goal of becoming capability-based, rather than threat-based, in its focus. This program, which was named the Joint Capability Technology Demonstration (JCTD) Program, includes many of the positive aspects of the ACTD program, as well as improvements to meet new and evolving defense challenges. The process will integrate the ACTD program with the new Joint Integration and Development System (JCIDS) developed by the Joint Chiefs of Staff (JCS).

Current ACTD processes will be transited to the improved JCTD program over a 3-5 year transition period, with the intent of having the JCTDs replace the ACTDs. The new process will focus on joint and transformational technologies that are initiated in Science and Technology (S&T), and carried through the difficult transition stage. The new JCTD business model will also include a Defense Acquisition Executive (DAE) pilot program that will take a limited number of "joint peculiar" JCTDs past Milestone B, into procurement, followed by initial sustainment – a "cradle-to-grave" approach.

Similar to the ACTD program, the JCTD program possesses three possible transition models post-demonstration. They are:

- <u>Transition to Program of Record (POR)</u>. The military utility of the program has been successfully demonstrated, and the concepts will be adopted by the

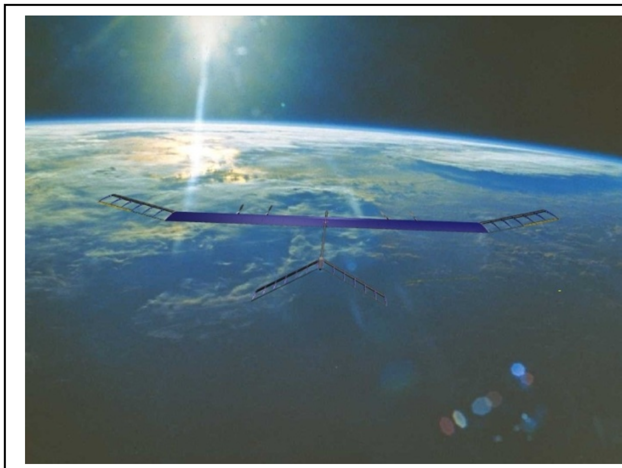
warfighters. Products will be transferred to a new/current POR or GSA (Government Services Administration) schedule. The acquisition of additional capability will also be funded.

- Interim Capability to Meet Needs of the Warfighter. Military utility has been successfully demonstrated, and the concepts will be adopted by the warfighter. However, the products may or may not have been sent to a POR. This interim capability fully meets the warfighter's needs and is being maintained.
- Return to Technology Base. The military utility is deemed to be not successfully demonstrated. Relevant components or capabilities may be incorporated into other systems, returned to the technology base, or terminated.

C. ZEPHYR JCTD

Zephyr is a solar-powered, HALE UAV concept conceived by QinetiQ Ltd, UK. Its aim is to provide an affordable solution to a number of military gaps, particularly in the areas of deep reach, surveillance, and communication relay. The Zephyr prototype is shown in Figure 5.

Figure 5. Zephyr Prototype [From 22]



Zephyr is designed to operate for an extended duration of three months during which the aircraft would not descend below 50,000 feet altitude. The general design parameters of Zephyr are given in Table 3. Zephyr Design Parameter [From 19]The system's long endurance will enable it to perform many tactical roles requiring long loiter time over target area, thereby making an important contribution to maintaining battle space awareness. Moreover, due to its relatively small size and the ability to sustain at a high altitude during operation, Zephyr will be ensured of its low observability and low vulnerability, which is ideal for missions that are considered high risk for other airborne platform.

Table 3. Zephyr Design Parameter [From 19]

Systems	Mass (kg)
Platform	< 30
Battery	9
Payload	2
Solar Array	3.2

In 2007, Zephyr was selected as a JCTD candidate to address the current operation voids for persistence ISR and C3 capabilities. The schedule of the Zephyr JCTD program is planned to span over a two-year period, starting from 2008. The program is sub-divided into five partially overlapping phases, as follows:

Phase 1 – Airframe development and validation

Phase 2 – Operation system requirement and Low Rate Initial Production (LRIP) preparations

Phase 3 – LRIP, operational documentation and training

Phase 4 – Preparations for volume production and military certification

Phase 5 – Volume production

[Refer to Appendix A for the detailed Zephyr JCTD program.]

Phase 1 of the program was concluded in August 2008 at Yuma Proving Ground, Arizona with the demonstration of the aircraft, carrying a communications test payload weighing two kilograms, sustaining a flight endurance of 82 hour and 37 minutes [20].

D. BUSINESS CASE ANALYSES

A Business Case Analysis [21] (BCA) is a fundamental tool used by decision-makers to evaluate different alternatives and then decide on the best courses of action required in the allocation of scarce resources. It is a structural and systematic methodology that examines not only the cost, but also other quantifiable and non-quantifiable factors that support an investment decision.

The BCA is an iterative process that is conducted and updated as required throughout the lifecycle of the program. A typical BCA would include the following elements:

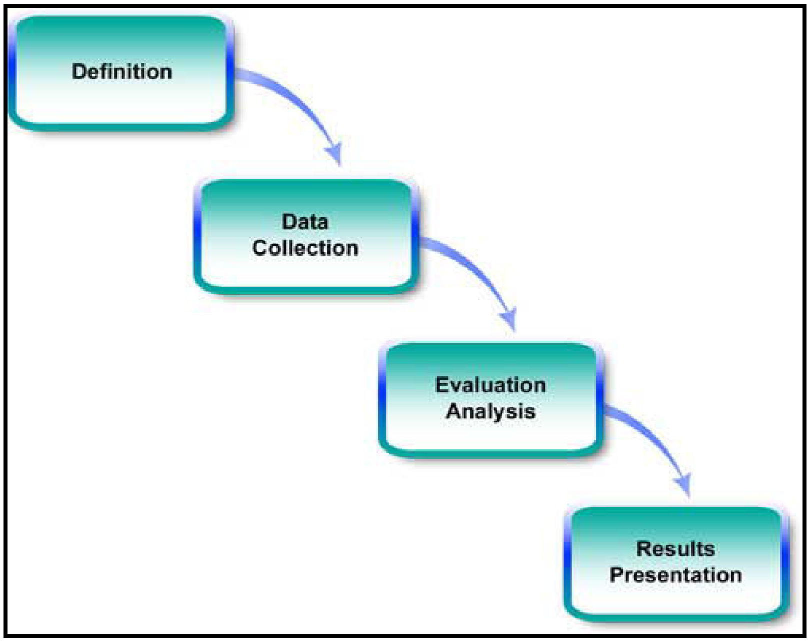
- the objectives of the case
- the methods, assumptions and constraints
- possible alternatives, including the current status quo
- the costs and benefits of each alternative in the scenario
- sensitivity analysis and risk analysis
- conclusions and suitable recommendations

As a decision-making tool, the quality and reliability of the BCA is crucial in enabling the decision-maker to make an informed choice. As such, the BCA process provides the decision-maker with relevant insights as to how the project supports the strategic objectives and how it can achieve them. This assessment is structured such that pertinent information on the scope, alternatives, costs, and benefits are laid out clearly, with potential risks highlighted so that the decision-maker can decide whether or not to invest in the project.

As no two BCAs are alike in their objectives, assumptions, constraints, risk, and operating scenario, it is necessary that each BCA is customized for the particular case

given the operating environment, i.e., there is no one-size-fits-all solution. However, a generic BCA methodology can be described as a four-phase process, as shown in Figure 6. BCA Methodology [From 21]

Figure 6. BCA Methodology [From 21]



The steps in the process are:

1. Definition

In the first phase, the scope, assumptions, and constraints will be defined to guide the analysis. Alternative options are also explored to ensure that a minimum of two outcomes (one of which could be maintaining the status quo) are available at the end of the analysis.

2. Data Collection

In the second phase, a data collection plan is devised, so that the types of data required, data sources, and how they can be obtained, can be mapped out. Models must also be developed so that the data can be categorized and stored, while preserving its

integrity. Data normalization is also applied where required. Where the data is not available, estimates can be made, as long as they can be justified, and the methodology adopted explained clearly.

3. Evaluation Analysis

The third phase is where most of the actual BCA work is accomplished. Data analysis is performed to build the case for each alternative. Alternatives are compared against the baseline and with one another to determine the alternative that provides the optimal cost-benefit combination. Risk analysis is performed to identify the set of risks associated with each alternative, along with proposed risk-mitigating strategies. Sensitivity analysis is also performed to provide insights as to how changes in key parameters or underlying assumptions and constraints that were made could influence the outcome of the analysis.

4. Results Presentation

The fourth and final phase is where the results are communicated to the decision-maker. The information presented should be concise, with relevant supporting evidence from the previous phases. A conclusion and recommended course of action should also be provided to the decision-maker based on the objectives defined in Phase 1.

In summary, once completed, the BCA should be able to determine the following:

- the relative cost vs. benefits of different strategies
- the methods and rationale used to quantify benefits and costs
- the impact and value of Performance / Cost / Schedule / Sustainment tradeoffs
- data required to support and justify the strategy
- sensitivity of the data to change
- analysis and classification of risks
- a recommendation and summary of the implementation plan for proceeding with the best value alternative

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III. ZEPHYR BUSINESS CASE ANALYSIS

This section details the conduct of a BCA of deploying the Zephyr system, which analysis uses the Global Observer, a liquid hydrogen-fueled HALE UAV as a comparison.

The analysis starts by defining the scenario under which the UAVs will be deployed with emphasis on 24/7/265 ISR and communications relay missions. The available data will be analyzed, followed by the computation of Return on Investment (ROI) as well as a sensitivity analysis on the key results obtained. In addition, the ratio of the number of Zephyr system equivalence to the number of Global Observer is computed to provide us with an insight on the number of Zephyr system equivalent can be purchased and sustained over its lifecycles. Finally, a general risk assessment for the Zephyr system is made.

The analysis is modeled closely on the BCA carried out by Lim [9], as comparison is made against it. This is to ensure that the BCA conducted on Zephyr has the same baseline as that of Global Observer, and is thus unbiased.

A. OPERATIONAL SCENARIO

There are six areas of interest for strategic deployment of the systems to provide continuous ISR coverage, as well as providing tactical battlefield communication. These six regions form the tasking requirements for our analytical scenarios and are summarized as follows:

- <u>Trans-Sahara Region.</u> To support the Trans-Sahara Counter-terrorism Initiative (TSCI).
- <u>Afghanistan / Pakistan.</u> To support the on-going military operations in Afghanistan and Pakistan.
- <u>Iraq.</u> To support Task Force ODIN (Observe, Detect, Identify and Neutralize) and on-going peace-support operations in Iraq.
- <u>Colombia.</u> To support the on-going fight against the illegal flow of drugs into CONUS (CONtinental United States).

- Strait of Malacca. To maintain surveillance of possible terrorist activities that would restrict a ship's passage across the narrow strait.
- China / North Korea. To maintain U.S. surveillance of nuclear facilities and military defenses in the region.

1. UAV Operating Bases

For the purpose of comparison, it is assumed that Zephyr is launched from any one of the following three existing or designated-future operating bases, which is aligned with the assumed Global Observer operating bases.

These bases are:

- Beale Air Force Base (California, USA) – Current Global Hawk Operating Base.
- Anderson Air Force Base (Guam) – New Global Hawk Forward Operating Base to be ready in 2009.
- Al Dhafra Air Base (United Arab Emirates) – Existing Expeditionary Global Hawk Forward Operating Base.

2. Selection of UAV Operating Base

Table 4 illustrates the distances from the nearest operating base (correct to the nearest ten nautical miles) to the various Areas of Operations (AO). For the purpose of distance computation, the following locations were used as proxy for the respective AO:

- Trans-Sahara Region: Niger-Algeria-Mali boundary
- Afghanistan / Pakistan: Kabul
- Iraq: Baghdad
- Colombia: Bogota
- Strait of Malacca: Singapore
- China / North Korea – Pyongyang

Table 4. Selection of Operating Bases to Launch the UAV

	Area of Operation	Nearest UAV Operating Base	Distance (nm)
1	Trans-Sahara Region	Al Dhafra AB	2810
2	Afghanistan / Pakistan	Al Dhafra AB	980
3	Iraq	Al Dhafra AB	760
4	Colombia	Beale AFB	3290
5	Strait of Malacca	Anderson AFB	2540
6	China / North Korea	Anderson AFB	1860

B. DATA ANALYSIS

The following sections provide an analysis of the data based on the given operational scenario.

1. Number of UAVs Required

A mission flying profile for the UAV can be divided into three parts; ingress, loiters, and egress. The UAV is launched from its operating base and ingress to the designated AO, then it will loiter above the AO and execute its mission until it runs out of fuel and egress back to the operating base for maintenance. Before the UAV flies back the operating base, the second UAV would have arrive to replace it so that the mission is not disrupted. When the second UAV fuel is low, the third UAV would have arrived to replace and the second UAV will return to the operating base.

Figure 7 illustrates the typical mission sortie profile of the UAV.

Figure 7. Typical Mission Sortie Profile of the UAV [From 9]

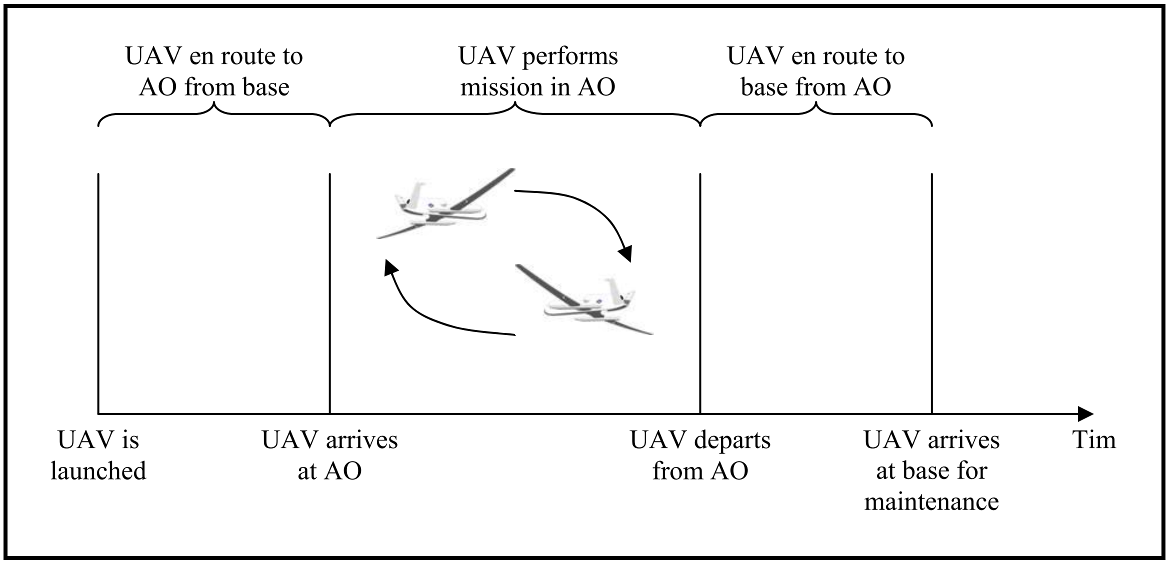


Table 5 summarizes the cruise speeds and flight endurance times for both the Zephyr and the Global Observer used in the calculations:

Table 5. Cruise Speed and Endurance Times for Zephyr and Global Observer

Attribute	Zephyr	Global Observer [9]
Cruise Speed	15 mph (13 knots)	110 knots
Endurance	3 months (2160hrs)	7 days (168hrs)

The following key assumptions were made in the computation of the minimum number of UAVs required:

- The returning UAV will have an hour of spare flight time (i.e., reserve fuel load) remaining when it arrives back at base.
- The time required for maintenance is assumed to take an average of 36 hours after each mission sortie. This takes into account the fact that maintenance can be as short as a few hours (for normal refueling operations), or possibly as

long as a week at a stretch (for complete structural maintenance and inspection) after the UAV is deployed for a certain number of missions.

- Weather factors such as headwind or tailwind, which may affect the distance covered vis-à-vis the endurance of the UAV, is not taken into account in the analysis.
- The time taken to climb to cruise altitude is assumed to be negligible compared to the UAV's flight endurance.
- Air spares for redundancy coverage are not required.
- Ground spares were not included in the calculations at this point, but will be factored in subsequently for the mission to each of the AOs.

For each AO, the number of UAVs required is computed based on the following formula:

$$\begin{aligned}&\text{Number of UAVs Required}\\&= \left\lceil \frac{\text{Mission Cycle Time}}{\text{UAV Time On-Station}} \right\rceil \text{ x Number of UAVs required on-station}\\&\quad + 1 \text{ Ground Spare}\end{aligned}$$

where:

$$\begin{aligned}\text{Mission Cycle Time} &= \text{UAV Time On-Station} + \text{UAV Transit Time}\\&\quad + \text{UAV Maintenance Time}\end{aligned}$$

$\lceil x \rceil$ is the ceiling function of x

The UAV requirements are summarized in Table 6. UAV Requirements for Mission to Respective AO.

Table 6. UAV Requirements for Mission to Respective AO

	Area of Operation	Distance (nm)	# Zephyr Required (incl. spare)
1	Trans-Sahara Region	2810	3
2	Afghanistan / Pakistan	980	3
3	Iraq	760	3
4	Colombia	3290	3
5	Strait of Malacca	2540	3
6	China / North Korea	1860	3
Total			**18**

Based on the operational scenario considered, a total fleet size of 18 Zephyrs are required to provide 24/7/365 ISR and communications capabilities. For the Global Observer, a total fleet size of 20 units of UAVs is required for provide similar ISR and communication capabilities.

2. Life Cycle Cost Estimates

The LCCE for both Zephyr and Global Observer are computed over a period of 15 years based on the following Work Breakdown Structure (WBS):

Investment

- Aircraft cost
- Ground Control System (GCS) cost
- Payload cost

Operation and Support

- Fuel cost
- Maintenance and Repair cost

To compute and compare the LCCE of Zephyr vis-à-vis the Global Observer, the following key cost considerations will be used. Manpower costs are assumed to be the

same for both, and they are therefore not considered in this analysis; all costs are computed in FY08$. Exchange rate for British Pound to U.S. dollars is 1.75.

a. Aircraft Cost

The Average Unit Cost (AUC) of Zephyr aircraft is calculated to be $1,738,000 (FY08$). This calculation is based on a Low Rate Initial Production (LRIP) of 6 aircrafts at £1,265,000 per aircraft and a full rate production of 10 aircraft per year, for four years, at £1,000,000 per aircraft [22].

The AUC of Global Observer is estimated to be $14,200,000 (FY$05).

b. Ground Control System

The GCS cost is calculated to be $217,000 (FY08$). This is based on an estimate that the payload is 5% to 20% of the AUC of the aircraft cost [22]. The average of this range (i.e. 12.5%) is used as our base case.

The GCS cost for Global Observer is estimated to be $1,400,000 (FY05$).

c. Payload Cost

The payload cost is calculated to be $217,000 (FY08$). This is based on an estimate that the payload is 5% to 20% of the AUC of the aircraft cost [22]. The average of this range (i.e. 12.5%) is used as our base case.

The payload cost for the Global Observer is estimated to be $5,000,000 (FY05$).

d. Fuel Cost

Zephyr is a solar-powered UAV and does not require fuel for its operations. Thus, the fuel cost associated to the Zephyr is zero. However, the fuel cost for the Global Observer is estimated to be $11,100,000 per year (FY05$).

e. Maintenance and Repair Costs

Estimated annual maintenance and repair cost for Zephyr are $7,686,000 (FY08$) per year for a fleet of 18 aircraft. This is based on the cost of consumables and spares that was estimated at £100,000 per months for an extended in-theatre deployment of five aircraft [22].

The estimated annual maintenance and repair cost for the Global Observer is $2,100,000 (FY05$) per year.

Table 7 summarizes the costs associated with the WBS for both Zephyr and the Global Observer. The costs for Global Observer are converted to CY08$ using Naval Center for Cost Analysis (NCCA) Inflation Indices [23].

Table 7. Cruise Speed and Endurance Times for Global Hawk and Global Observer

Work Breakdown Structure	Global Observer [9]	Zephyr	Basis of Estimates for Zephyr
Investment			
Aircraft Cost (per unit)	15.3	1.7	Low Rate Initial Production (LRIP) of 6 aircrafts at £1,265,000 per aircraft and a full rate production of ten aircraft per year, for four years, at £1,000,000 per aircraft
Ground Control Station Cost (per unit)	1.5	2.2	Based on an estimate that the payload is 5% to 20% of the AUC of the aircraft cost. The average of this range (i.e. 12.5%) is used as our base case
Payload Cost (per unit)	5.4	2.2	Based on an estimate that the payload is 5% to 20% of the AUC of the aircraft cost. The average of this range (i.e. 12.5%) is used as our base case
Operation and Support			
Fuel Cost (per annum)	12.0	0	-
Maintenance and Repair Cost (per annum)	2.7	7.7	Based on an estimate of the cost of consumables and spares at £100,000 per months for an extended in-theatre deployment of five aircraft.

Table 8 summarizes the LCCE of the Zephyr and the Global Observer over a period of 15 years. It is assumed that the fuel cost and maintenance and repair costs remain constant over this period.

Table 8. Summary of Life Cycle Cost (FY08M$) for the Global Observer and Zephyr

Work Breakdown Structure	Global Observer	Zephyr	Delta, $	Delta,%
Investment				
• Aircraft Cost	306.0	31.3	274.7	89.8
• Ground Control Station Cost	30.0	3.9	26.1	87.0
• Payload Cost	107.9	3.9	104.0	96.4
Operation and Support				
• Fuel Cost	107.0	0	107.0	100
• Maintenance and Repair Cost	397.0	115.3	281.7	71.0
Total	**949.3**	**154.4**	**794.9**	**83.7**

The estimated LCCE of the Zephyr for 15 years is $154.4M (FY08$), compared to the Global Observer's LCCE of 949.3M (FY08$). This translates to a savings of $794,9M, which is approximately 83.7% of the Global Observer's LCCE.

C. RETURN ON INVESTMENT ANALYSIS

The approach for the Return on Investment (ROI) analysis is to establish a base case with quantitative benefits that can be attributed to the operational deployment of the Global Observer vis-à-vis the use of the Global Observer, as well as the potential savings in commercial satellite communications utilization.

The ROI calculation is given by the formula below:

$$ROI = \left(\frac{\text{Net Present Value of Savings}}{\text{Net Present Value of Investment}}\right)^{1/13} - 1$$

1. Base Case ROI

The base case ROI is computed over a period of 15 years from FY 08. The ROI computation is performed for two cases; one which does not include the costs of leasing commercial satellite bandwidth and one which does include these costs. The cost of using commercial satellite bandwidth is estimated to be \$40M (FY05\$), which is equivalent to \$41.8M (FY08\$). For both cases, it is assumed that the discount factor is zero for the computation of NPV.

For the purpose of comparison, it is assumed that the bandwidth usage for the annual in-theater communications remains at \$41.8M (FY08\$) for subsequent years, which translates to an annual potential savings of \$41.8M (FY08\$), or \$627M (FY08\$) for 15 years.

The ROI, without considering the cost avoidance of using commercial satellites for acquiring Zephyr, is as follows:

$$ROI = \left(\frac{Net\ Present\ Value\ of\ Savings}{Net\ Present\ Value\ of\ Investment}\right)^{1/15} - 1$$

$$= \left(\frac{949{,}300 - 154{,}404}{39{,}114}\right)^{1/15} - 1$$

$$= 22\%$$

The ROI, considering the cost avoidance of using commercial satellites for acquiring Zephyr, is as follows:

$$ROI = \left(\frac{Net\ Present\ Value\ of\ Savings}{Net\ Present\ Value\ of\ Investment}\right)^{1/15} - 1$$

$$= \left(\frac{949{,}300 - 154{,}404 + 627{,}000}{39{,}114}\right)^{\frac{1}{15}} - 1$$

$$= 27\%$$

2. Sensitivity Analysis

The purpose of sensitivity analysis is to determine the responsiveness of the model's results to uncertainty in the input data. This is important because input data typically contain undesired variations and analysis results could reflect this variation instead of the true input data value. Thus, sensitivity analysis provides decision-makers with confidence regarding the robustness of the model's varying input parameters.

For this study, the factors to be varied are as follow:

- Aircraft AUC – This factor is varied from \$1.5M (FY08\$) to 3.5M (FY08\$). High production costs would reduce the potential benefits of the Zephyr system.
- GCS/ Payload Cost – These factors varied from 5% to 20% of the aircraft AUC. The data given by the supplier is as such, and thus a sensitivity analysis is performed to determine the effect on the ROI.

It is assumed that the discount factor to compute NPV is zero. Table 9 summarizes the factors that varied for the sensitivity analysis. The fuel cost, maintenance and repair cost, and discount factors are fixed at zero, \$7.7M (FY08\$) and zero respectively.

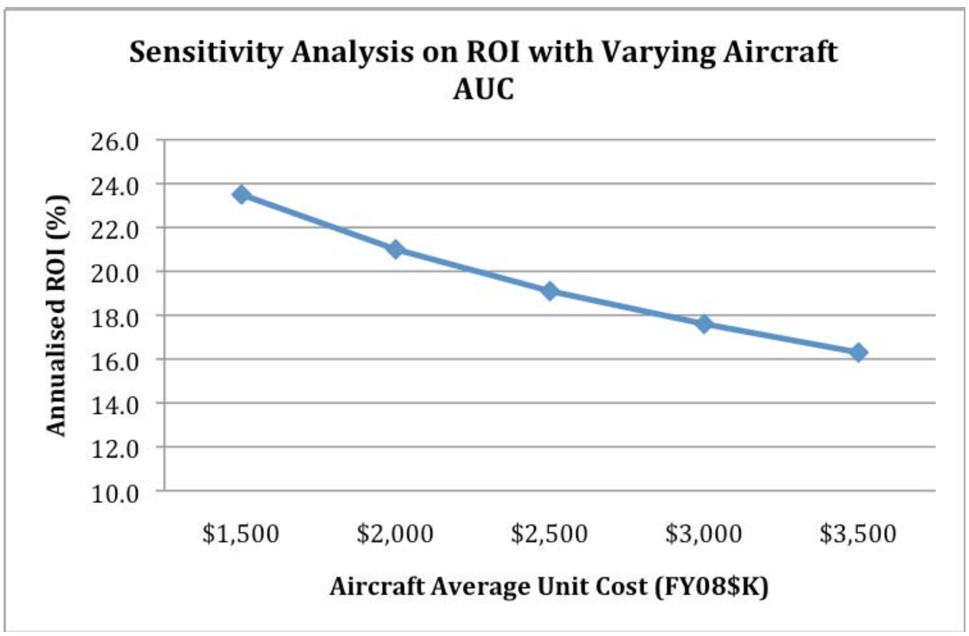
Table 9. Factors Varied for ROI Sensitivity Analysis

Analysis	AUC (FY08$M)	GCS (% of Aircraft AUC)	Payload (% of Aircraft AUC)
Base Case	$1.7	12.5%	12.5%
Aircraft AUC	**$1.5 to $3.5**	12.5% (of base case AUC)	12.5% (of base case AUC)
GCS Cost	$1.7	**5% to 20%**	12.5%
Payload Cost	$1.7	12.5%	**5% to 20%**

a. Aircraft AUC

Figure 8 shows the results of annualized ROI with varying aircraft average unit from $1.5M (FY08$) to $3.5M (FY08$).

Figure 8. Sensitivity Analysis on ROI with Varying Aircraft AUC

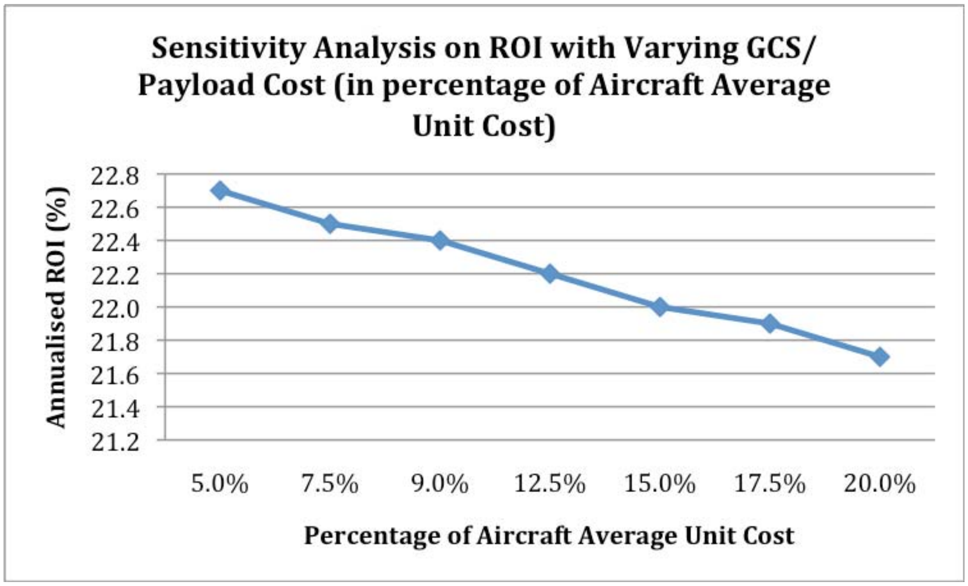


The ROI decreases from approximately 24% to 18% when aircraft AUC increases from $1.5M (FY08$) to $3.5M (FY08$). Even if the aircraft AUC is almost doubled, from $1.8M (FY08$) to $3.5M (FY08$), ROI remains positive, approximately 16%. This shows that investment in the Zephyr system is still attractive.

b. GCS/ Payload Cost

Figure 9 shows the results of annualized ROI with varying GCS cost or payload from 5% to 20% of the aircraft AUC.

Figure 9. Sensitivity Analysis on ROI with Varying GCS/ Payload Cost (in Percentage of Aircraft AUC)



ROI decreases from approximately 23% to 22% when the GCS cost increases from 5% to 20% of the aircraft AUC. The result is insensitive to this variation and, hence, has no significant impact on the ROI calculated.

D. RATIO OF INVESTMENT COST ANALYSIS

In addition to ROI and sensitivity analysis, it is also pertinent to examine the ratio of investment cost of the Zephyr system compared to the Global Observer system. Zephyr is a small UAV with limited payload capacity, and thus its ability to provide ISR and communications capabilities is significantly restricted as compared to Global Observer. From this angle, investment in the Zephyr system would seem unattractive. However, if the number of Zephyr systems that can be acquired, compared to the amount of investment required for one unit of Global Observer, is significant, acquiring Zephyr systems could be more attractive. In addition, if the supplier is able to push down the

costs of the Zephyr system, this would in turn increase the number of Zephyr systems that can be acquired, making the investment more attractive.

1. Ratio of Investment Cost for Zephyr System to Global Observer System

The investment costs for Zephyr and Global Observer systems to accomplish the missions defined in section A, is shown in Table 10. Investment Costs (FY08$M) for Single Zephyr and Global Observer Systems

Table 10. Investment Costs (FY08$M) for Single Zephyr and Global Observer Systems

	Global Observe	Zephyr
Aircraft cost (unit production cost)	$15.3	$1,74
Ground Control System (unit cost)	$1.53	$0.217
Payload Cost (unit cost)	$5.40	$0.217
Total	$22.2	$2.17

The base case calculation for the ratio of investment cost of Global Observer System and Zephyr System is as follows:

$$Ratio = \left(\frac{Investment\ Cost\ of\ Global\ Observer\ System}{Investment\ Cost\ of\ Zephyr\ System}\right)$$

$$= \left(\frac{22{,}249}{2{,}172}\right)$$

$$= 10$$

From the base case analysis, it can be seen that for every one unit of the Global Observer System purchased, ten units of the Zephyr system can be acquired. Table 11 shows the number of Zephyr systems that can be acquired given a reduction in the unit cost of the Zephyr system.

Table 11. Number of Zephyr System Given Reduction in Unit Cost

Unit Cost of Zephyr System (FY08$M)	No. of Zephyr Systems (Units)
$ 2.2	10
$ 1.8	12
$ 1.4	15
$ 1.0	22
$ 0.6	37

When the supplier reduces the unit cost for Zephyr systems from $2.2 (FY08$M) to $0.6 (FY08$M), the number of Zephyr systems that can be acquired increases from ten units to 37 units. As the number of Zephyr units increases, the attractiveness of the investment increases; this could drive the supplier to keep the unit cost of the Zephyr system as low as possible.

E. RATIO OF NET PRESENT VALUE OF LIFE CYCLE COST ESTIMATES ANALYSIS

In addition to the ratio of investment cost for the Global Observer system compared to the Zephyr system, it is also appropriate to look at the respective Net Present Value (NPV) of their LCCEs. The LCCE is the estimated total cost incurred, expressed in present worth, for a particular system over its entire useful life. This estimate includes research and development (R&D), investment, operation and support (O&S), and disposal cost. This is useful as the LCCE not only provides the present cost of procuring a system, but also the future cost of use over its lifetime. Thus, if the ratio of these NPVs is taken into consideration, then the number of Zephyr systems that could be acquired and supported throughout its lifetime, given the amount of capital needed to acquire and support one unit of the Global Observer system, can be determined. The higher the ratio, the more attractive the investment in the Zephyr system over the Global Observer system becomes. For our LCC estimates, only investment and O&S costs are considered.

1. Base Case Ratio of NPV of LCCE

The base case NPV of LCCE is computed over a period of 15 years with the base year fixed at FY 08 and a discount rate of zero percent. The computation of NPV of LCCE of the system is as follows:

$$NPV = PV\ of\ LCCE\ for\ Investment + PV\ of\ LCCE\ for\ O\&S$$

$$NPV = PV\ of\ LCCE\ for\ Investment + A\left(\frac{(1+i)^n - 1}{i\,(1+i)^n}\right)$$

Where:

- PV of Investment includes PV Aircraft Cost, PV GCS Cost and PV Payload Cost over *n* period,
- *A* is the annual O&S Cost,
- *i* is the discount factor,
- *n* is the number of periods (years) of the system's lifetime.

For this analysis, all costs are expressed in FY08$.

If the discount rate is zero percent, which means that the value of money does not decrease over time, NPV is calculated based on the following:

$$NPV = PV\ of\ LCCE\ for\ Investment + (n \times A)$$

The PV of LCCE for investment and O&S are based on the estimates derived for the base case ROI analysis presented in Table 7. The results of the LCC estimates are presented in Table 8 with the NPVs of the systems is the summation of their respective investment and O&S PVs. The NPV for Global Observer is $949,300K (FY08$) and the NPV for Zephyr system is $154,404K (FY08$), assuming a discount factor of zero.

Thus, the ratio of NPV of LCCE for the Global Observer System compared to LCCE for the Zephyr System, over a 15-year period, is as follows:

$$Ratio = \left(\frac{NPV\ of\ LCCE\ for\ Global\ Observer\ System}{NPV\ of\ LCCE\ for Zephyr\ System}\right)$$

$$= \left(\frac{\$949{,}300K}{\$154{,}404K}\right)$$

$$= \left(\frac{\$949{,}300K}{\$154{,}404K}\right)$$

$$= 6$$

The ratio of NPV of LCCE for the Global Observer system as compared to LCC estimate for the Zephyr system is six. This implies that six units of the Zephyr system can be acquired and supported over its lifetime, given the amount of capital to acquire and support one unit Global Observer.

2. Sensitivity Analysis

A sensitivity analysis is conducted on the base case analysis to provide insights and confidence to decision-makers regarding the analysis when subjected to uncertainties in the factors. For this study, the factors to be varied are as follows:

- Discount Factor – This factor varies from 0% to 20%. A large discount factor would affect the LCCE for Zephyr in terms of total cost.
- Aircraft AUC – This factor varies from \$2.2M (FY08\$) to \$0.6M (FY08\$). A lower aircraft AUC would affect the investment cost, which will invariably affect the LCCE for Zephyr.
- GCS/ Payload Cost – These factors vary from 5% to 20% of the aircraft AUC. This data range is provided by the supplier and thus a sensitivity analysis is performed to determine the effect on the result.
- O&S Cost – This factor is varied from \$7.7M (FY08\$) to \$4.0M (FY08\$). A lower O&S cost would translate to a lower LCCE for Zephyr.

Table 12 summarizes the factors that are varied for the sensitivity analysis. The fuel cost, maintenance and repair cost, and discount factors are fixed at zero, $7.7M (FY08$), and zero respectively.

Table 12. Factors Varied for Ratio of NPV of LCCE Sensitivity Analysis

Analysis	**AUC (FY08$M)**	**GCS (% of Aircraft AUC)**	**Payload (% of Aircraft AUC)**	**Maintenance & Repair (FY08$M)**	**Discount Factor (%)**
Base Case	$1.7	12.5%	12.5%	$7.7	0%
Aircraft AUC	**$2.2 to $0.6**	12.5% (of base case AUC)	12.5% (of base case AUC)	$7.7	**0% to 20%**
GCS Cost	$1.7	**5% and 20%**	12.5%	$7.7	**0% to 20%**
Payload Cost	$1.7	12.5%	**5% and 20%**	$7.7	**0% to 20%**
Maintenance & Repair cost	$1.7	12.5%	12.5%	**$7.7M to $4.0M**	**0% to 20%**

a. Aircraft AUC

The aircraft AUC for the Zephyr system varies from $2,200K (FY08$) to $600K (FY08$) with a discount factor varying from 0% to 20% and the payload/GCS is fixed at 12.5% of the aircraft AUC used in our base case analysis. This GCS/Payload cost will not change as we vary our aircraft AUC in this sensitivity analysis.

The results of the ratio of NPV to LCCE for the Global Observer system to the Zephyr system with a varying aircraft AUC is shown in Figure 10.

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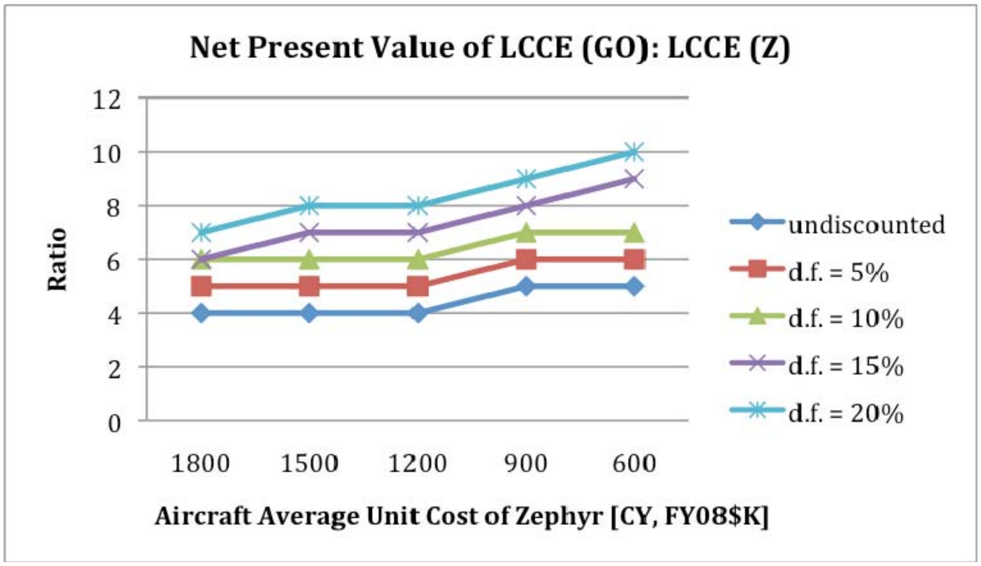
Figure 10. Ratio of NPV of LCCE for Global Observer System to Zephyr System with Varying Aircraft AUC



As the Zephyr aircraft AUC decreases or/and the discount factor increases, the ratio of NPV to LCCE for the Global Observer system compared to the Zephyr system increases. This is because as the Zephyr aircraft AUC decreases, more units of the Zephyr system can be acquired and supported throughout its life cycle, given the capital to acquire and support one unit of the Global Observer system. Similarly, when the discount rate increases, the annual O&S cost will become less expensive over the years and thus drive down costs.

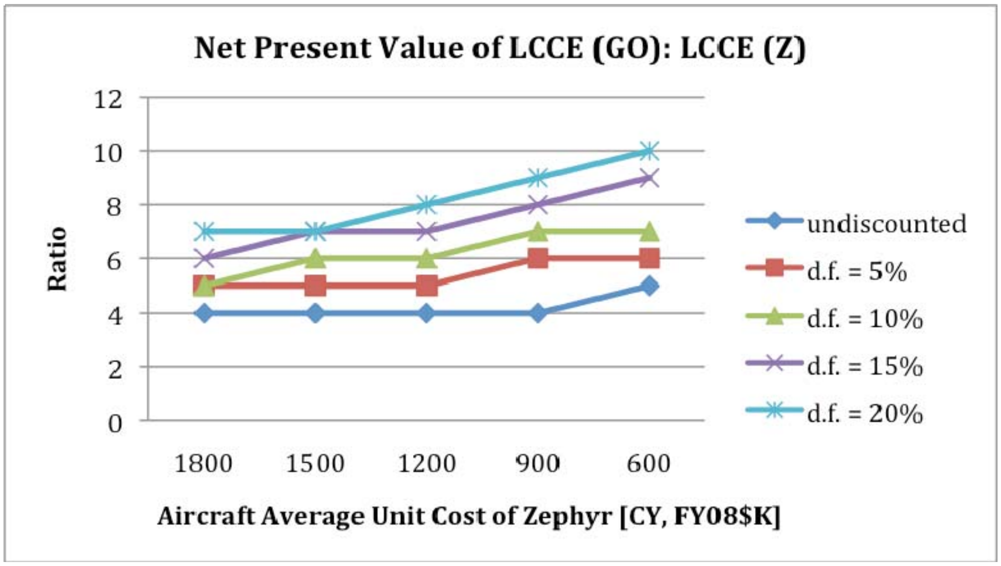
The ratio ranges from four to ten, which implies that from four to ten units of the Zephyr system can be acquired and supported throughout its life cycle given the capital to acquire and support one unit of the Global Observer system.

b. GCS/Payload Cost

The GCS/Payload cost for Zephyr system varies from 5% to 20% of the aircraft AUC. This analysis is carried out in two parts, where the extreme values for the GCS/Payload cost for Zephyr system are fixed at 5% and 20% of the aircraft AUC is pegged to the value used for the base case. The discount factor varies from 0% to 20% and the aircraft AUC varies from $2,200K (FY08$) to $600K (FY08$).

(1) GCS/Payload cost for Zephyr system fixed at 5%. The results of the ratio of NPV to LCCE for the Global Observer system compared to the Zephyr system with GCS/Payload fixed at 5% is shown in Figure 11.

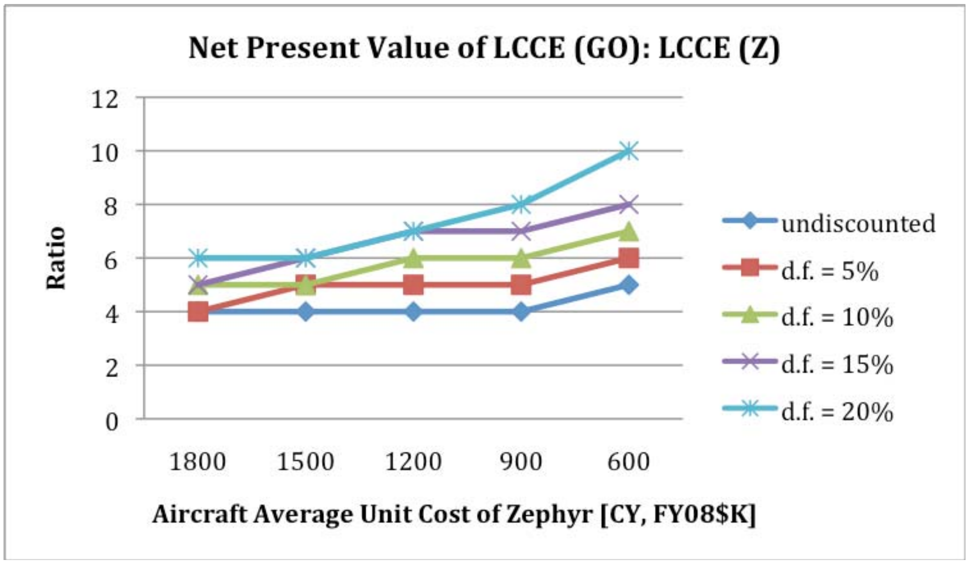
Figure 11. Ratio of NPV of LCCE for Global Observer System to Zephyr System with Varying AUC and GCS/ Payload fixed at 5%



As the Zephyr aircraft AUC decreases or/and the discount factor increases, the ratio of the NPV to LCCE for Global Observer system compared to the Zephyr system increases. The ratio ranges from four to ten, which implies that from four units to ten units of the Zephyr system can be acquired and supported throughout its life cycle, given the capital to acquire and support one unit of the Global Observer system. This is similar to the analysis where the GCS/Payload cost for the Zephyr system is fixed at 12.5%.

(2) GCS/ Payload cost for Zephyr system fixed at 20%.The results of the ratio of NPV to LCCE for the Global Observer system compared to the Zephyr system with GCS/Payload fixed at 20% is shown in Figure 12.

Figure 12. Ratio of NPV of LCCE for Global Observer System to Zephyr System with Varying AUC and GCS/ Payload fixed at 20%



As Zephyr aircraft AUC decreases or/and the discount factor increases, the ratio of the NPV of LCCE for the Global Observer system compared to the Zephyr system increases. The ratio ranges from four to ten, which implies that from four to ten units of the Zephyr system can be acquired and supported throughout its life cycle, given the capital to acquire and support one unit of the Global Observer system. This is similar to the analysis where the GCS/Payload cost for the Zephyr system is fixed at 12.5%.

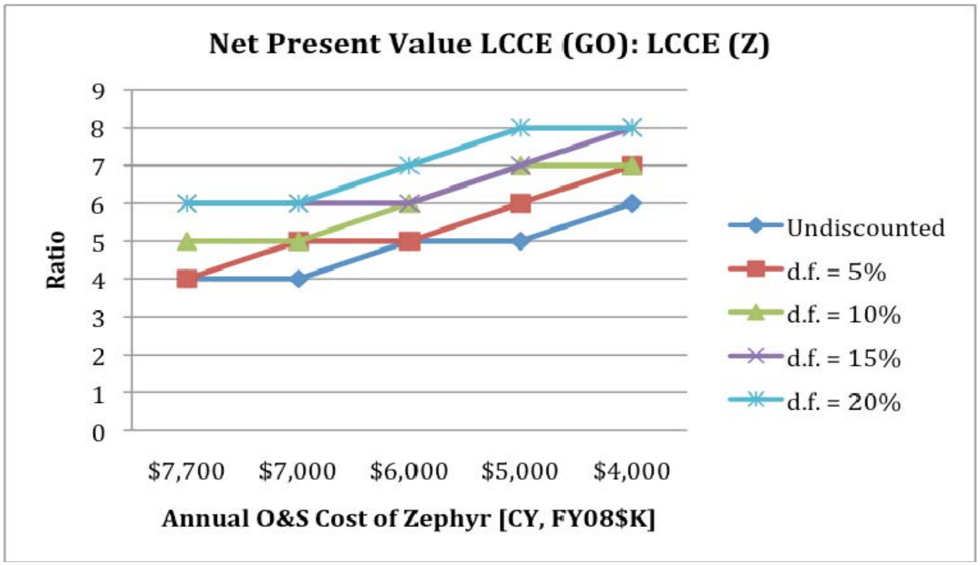
The GCS/Payload cost for the Zephyr system does not change the results of the ratio to the NPV of LCCE for the Global Observer system compared to Zephyr system and thus it is insensitive in this analysis.

b. O&S Cost

The annual O&S cost for the Zephyr system varies from $7,700 (FY08$K) to $4,000 (FY08$K) over its 15-year life cycle period, with the discount factor varying from 0% to 20%.

The results of the ratio of NPV to LCCE for the Global Observer system compared to the Zephyr system with a varying O&S cost is shown in Figure 13.

Figure 13. Ratio of NPV of LCCE for Global Observer System to Zephyr System with Varying O&S Cost



As the annual O&S cost decreases or/and the discount factor increases, the ratio of the NPV to LCCE for the Global Observer system compared to the Zephyr system increases. This is because as the annual O&S cost decreases, more units of the Zephyr system can be acquired and supported throughout its life cycle, given the capital to acquire and support one unit of the Global Observer system. Similarly, when the discount rate increases, the annual O&S cost becomes less expensive over the years, and thus drives Zephyr's cost down further.

The ratio ranges from four to eight, which implies that from four ten units of the Zephyr system can be acquired and supported throughout its life cycle, given the capital to acquire and support one unit of the Global Observer system.

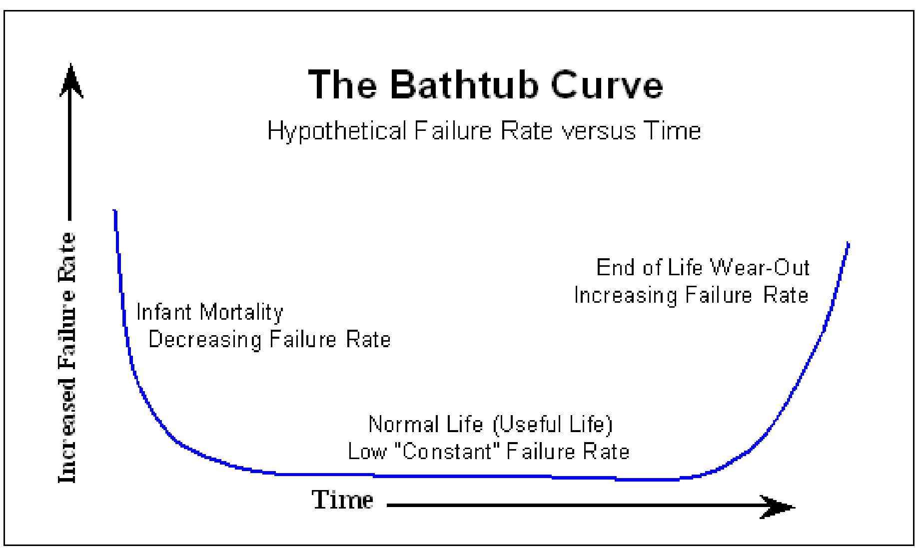
F. RISK ANALYSIS

While conducting the analysis of the ROI and LCCE for Zephyr is essential for any BCA, it is also important to look at the potential risk involved in this solar power concept that provides Zephyr's long flight endurance.

The concept of solar power has been in the industrial base for a while and is used in many areas, such as solar thermal and electrical generation. However, the use of solar power in HALE UAVs is a recent concept and not many developers have claimed success in its development yet. According to UAV International [4], all solar-powered UAV systems are still in the "proof of concept/development continuing" stage, which sees developers and optimistic investors putting enormous efforts and investments into ensuring that this concept is fundamentally sound and feasible.

As with all new concepts or products, there are risks involved. One of the risks is its low reliability (high failure rate) in the early stage of the system's life cycle, or its "infant mortality stage" as characterized by the bathtub curve in Figure 14.

Figure 14. Bathtub Curve [From 24]



These failures are typically caused by defects that are designed into or built into solar-powered UAVs. Depending on how efficient manufacturers are in detecting and remedying these faults during the testing phase, the high failure rate of the systems might spill over into the early stages of actual operations, which is highly unacceptable if the Zephyr is to be deployed on a critical mission.

Although Zephyr has claimed successes in many of its flight demonstrations, including the latest flight demonstration at the Yuma Proving Ground where a record flight endurance of 82 hours and 37 minutes [20] was recorded, the reliability of the systems should be seriously considered if Zephyr is to be deployed for any critical operations at the early stage of its use.

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IV. CONCLUSION AND RECOMMENDATIONS

This report has presented a generic structure for performing a business case analysis, with specific application to the Zephyr JCTD. The BCA compares the performance of Zephyr with Global Observer (augmented with existing commercial satellite communications networks) in an operational scenario consisting of a 24/7/365 ISR and communications mission. Life Cycle Costs (LCC) consist of investment costs, as well as the O&S of the platform over a 15-year period.

The key results of the business case analyses are summarized as follows:

- The total LCCE savings for acquiring and operating Zephyr over Global Observer over 15 year period is estimated to be $794M (FY08$) starting from FY08.
  - The investment savings is $405M (FY08$), or approximately 91% of the investment cost for Global Observer.
  - The operating and support savings is $389M (FY08$), or approximately 77% of the operating and support cost for Global Observer.
- There is also an estimated potential cost avoidance of $41.8M (FY08$) per annum on commercial satellite bandwidth usage if Zephyr can be deployed to provide tactical battlefield communications over the area of interest, an addition to its ISR mission.
- The base case annualized compounded ROI over a 15-year period starting from FY08 is 22%, based on a NPV saving of $793,497K (FY08$).
- The base case annualized ROI decreases to about 16% when the Zephyr aircraft AUC increases from $1.8M to $3.5M (FY08$), almost doubling the estimated aircraft AUC used in the base case analysis.
- The base case annualized ROI does change significantly when the CGS cost or the payload is varied from 5% to 20% of the aircraft AUC. The ROI remains at approximately 22% to 23%.

- The number of Zephyr systems that can be purchased given the funds to purchase one unit of the Global Observer system is ten, at a cost of $2,200K (FY08$). This increases to 37 when the unit cost of the Zephyr system is reduced to $600K (FY08$) for a 15-year period starting from FY08.
- The number of Zephyr systems that can be purchased and supported given the funds to purchase and support one unit of Global Observer systems, is six at a cost of $154,404K (FY08$) for a 15-year period starting from FY08.
- The number of Zephyr systems than can be acquired and supported given the funds to acquire and support one unit of the Global Observer system ranges from four to ten when the aircraft AUC decreases from $1.8M (FY08$) to $0.6M (FY08$) with a discount rate increasing from 0% to 20%.
- The number of Zephyr systems than can be acquired and supported given the funds to acquire and support one unit of the Global Observer system remains from four to ten when the aircraft AUC decreases from $1.8M (FY08$) to $0.6M (FY08$) with a discount rate increases from 0% to 20% and a GCS or payload cost which varies from 5% to 20% of the Zephyr aircraft AUC.
- The number of Zephyr systems than can be acquired and supported given the funds to acquire and support one unit of the Global Observer systems ranges from four to ten when the annual O&S cost decreases from $7.7M (FY08$) to $4M (FY08$) with a discount rate increasing from 0% to 20%.
- The reliability of the Zephyr system remains uncertain even though it has claimed success in its flight demonstrations.

The benefits of the Zephyr should not be limited to the factors presented in this study, as these factors are by no means a comprehensive list of factors by which the Zephyr ought to be measured. The very fact of a HALE UAV achieving 82 hours and 37 minutes of flight endurance is already a significant milestone for the solar-powered UAV concept, especially given that currently, operational UAVs can achieve no more than two

days of flight endurance. Thus, Zephyr appears to be a worthwhile investment that can provide the DoD with a new capability in round-the-clock ISR and battlefield communications.

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APPENDIX A. DETAILS OF ZEPHYR JCTD PROGRAM [24]

A. PHASE 1: AIRFRAME DEVELOPMENT AND VALIDATION

This work is focused on development and validation of the Zephyr 7 platform, which will form the basis of operational capability, and demonstration of the system's ability to provide a solution for a US JUONS.

Two main strands of activity are:

- Re-flight of the existing Zephyr 6 system with the objective of a) demonstrating in-flight operation of a JUONS payload and b) de-risking the Zephyr 7 development program by providing an early flight test of some of the key subsystems (e.g., direct-drive motors) that are proposed for Zephyr 7. Preparations for this demonstration are already underway and the flight test is scheduled for June 2008.
- Detailed design, assembly, integration, ground test and flight validation of the Zephyr 7 aero-structural design with the aim of confirming its flight efficiency and ability to meet the 2009 performance targets as outlined in section 3. The Zephyr 7 proving flight is provisionally scheduled for Summer 2009.

The design specifications for the Zephyr 7 airframe are expected to be finalized in Autumn 2008 and confirmed as appropriate for operational use following the validation flight in Summer 2009.

B. PHASE 2: OPERATIONAL SYSTEMS REQUIREMENTS AND LRIP PREPARATIONS

This Phase covers a number of activities that are needed to provide a complete operational system capability and to enable the start of Low Rate Initial Production (LRIP). The design specifications of the operational system components (other than airframe) are expected to be completed by Summer 2009.

The principal tasks in this Phase are:

- Operational system requirements capture and design specification for:
  - Operational system Ground Control Station (GCS): The GCS to be used to support the Zephyr 7 aero-structural validation flight in Summer 2009 will be an upgraded version of the Zephyr 6 GCS, which has been designed principally for flight trial use. This system will be upgraded to an operational capability by implementing a number of changes aimed at reducing the operator workload and thereby enabling system operation with a reduced crew.
  - Operational system communication links: Potential improvements to the existing Zephyr communication links are to be reviewed with the aim of improving link robustness and security in an operational environment. These improvements will involve implementation of digital communications links.
  - Transponders and any other devices required by the regulatory authorities, to be captured in a Minimum Equipment List
  - Network connectivity and interoperability with other command, control and communication systems
- Preparatory work for LRIP, including
  - Negotiation with and appointment of a US production partner. Key considerations in the selection of a production partner include the following:
    - Future volume production capability (workshop facility and workforce size issues);
    - Skilled workforce (technical competency and training issues);
    - Appropriate cost base for volume production (wage and accommodation cost issues);

- Logistics for transport and in-service support;
- Supply base management;
- Adaptability for innovation within relatively small production runs;
- Experience of aircraft type certification and production quality systems.

- Partner review of production processes and setting up of necessary tooling and workshops. As an input to this activity, QinetiQ will provide a technical data pack comprised of the following items, with the documentation developed in sufficient detail to enable any competent company to produce the complete system to the required level of quality from the information supplied:

  - Specifications;
  - Designs;
  - Bill of materials;
  - Tooling;
  - Test procedures;
  - Quality standards.

C. PHASE 3: LOW RATE INITIAL PRODUCTION (LRIP), OPERATIONAL DOCUMENTATION AND TRAINING

This phase will involve production of a small number (~5, TBC) of Zephyr 7 airframes by the selected production partner. A small number (~2, TBC) of GCS units will also be produced in this phase to support the delivered aircraft.

This activity will be initiated as early as possible in 2009. However, as the Zephyr 7 aero-structural design will not be fully validated until Summer 2009, and the operational GCS design specification will also not be finalized until the same time, initial

activity will focus on trial production runs aimed at establishing the efficiency of the airframe production processes and the procurement of long lead materials and parts for further builds.

A complete set of operational procedure documentation will be developed and delivered with the initial production platforms and GCS units. As a minimum, this is expected to include:

- Launch procedure;
- Flight operations procedure;
- Ground station operations procedure;
- Payload operation procedure(s);
- Recovery procedure;
- Ground handling procedure(s);
- Engineering maintenance procedure(s);
- Equipment storage requirements.

A training program covering all aspects of Zephyr operations from mission planning to ground handling, launch, flight operations, payload operations and platform recovery will be developed based on a Training Needs Analysis (TNA). It should be noted that some parts of the TNA cannot be undertaken until the operational GCS design is finalized (under Phase 2). Also, the TNA will need to be undertaken in close liaison with the end-user community. Equipment requirements to support the training program are to be confirmed but are expected to include a GCS and/or mission simulator. Training manuals will be provided based on the operational procedure documentation.

Planning will need to be undertaken to ensure that adequate support and maintenance measures are in place when the system enters operational use. Issues to be addressed include manpower requirements, in terms of numbers and skill sets, and spares policy (items, numbers, storage times and locations).

This phase will complete at the end of 2009 so that the delivered aircraft and GCS units are available for deployment and in-theatre operational use beginning in 2010.

D. PHASE 4: PREPARATIONS FOR VOLUME PRODUCTION AND MILITARY CERTIFICATION

This work covers those activities needed to prepare for routine production and certification of the system, and includes:

- Identification of requirements and necessary preparation for ongoing "volume" production (e.g., ~25-30 units per annum, TBC) by the production partner.
  - The critical suppliers to the Zephyr program will need to be contacted or visited to confirm and if necessary improve their ability to support a volume production operation. Where the Zephyr supply chain is currently single source, alternative suppliers should ideally be identified.
  - Among the issues to be considered in planning for future volume production is the limited lifetime of the solar cells and batteries. This will prevent the very long-term (>2 year) storage of fully integrated Zephyr platforms and large-scale production in advance of any specific mission requirement is therefore unlikely to be a sensible strategy. A cost-effective strategy which could ensure the timely availability of Zephyr platforms without risking sub-system degradation due to extended storage would be to procure the structure in a semi-complete form, without the power system components. Procurement and integration of the limited shelf-life components could then be undertaken on a relatively short timescale following notification of a specific mission requirement. This is considered a viable strategy subject to confirmation that the sub-system suppliers can deliver within a reasonable timescale.
- Construction and flight of a small number (~5, TBC) of additional aircraft in order to accumulate the flying hours needed to establish the system reliability and safety record and to achieve military certification.

E. PHASE 5: VOLUME PRODUCTION

This phase will start on completion of the preparatory activities under Phase 4 and confirmation of volume production orders.

Volume production requirements may be influenced not only by operational needs but also by the extent of component re-use and platform refurbishment. Previous flight trials have demonstrated that a Zephyr platform can be recovered essentially intact but operational experience will be required before usage statistics can be confirmed, e.g., in terms of average number of missions per platform, damage and loss rate, etc.

APPENDIX B. ESTIMATION OF ZEPHYR AUC

A. OBJECTIVE

The objective of this study is to estimate the Zephyr aircraft AUC by establishing a cost estimate relationship using the cost (response) as a function of flight endurance, minimum take-off weight, engine thrust and payload weight (regressors).

B. METHODOLOGY

The data used to establish the cost establish relationship is taken from open sources and is tabulated in table B1 below:

Table B1. UAVs Data Set

System	Payload (kg)	Endurance (hrs)	MTOW (kg)	Thrust (kW)	Cost USD (million)	Source
Predator	440	40.00	1040	73.00	3.20	[26]
Eagle Eye	136	4.00	1020	313.00	5.50	[27]
Altair	299	30.00	3266	708.00	8.00	[28]
Skywarrior	227	36.00	1500	99.00	8.00	[29]
Mariner	907	49.00	5000	708.00	13.00	[30]
Heron	250	40.00	1100	73.00	6.50	[30]
Darkstar	455	12.00	3091	-	10.00	[31]
Global Hawk	1360	36.00	14630	-	35.00	[32]
Global Observer	450	24.00	4100	-	18.50	[33]
Pioneer	34	5.00	205	19.00	0.90	[34]
Dragon Eye	2	0.75	3	-	0.07	[35]
Shadow	25	6.00	90	-	0.50	[36]
Polecat	450	4.00	-	-	27.00	[37]

Table B2 shows the regression analyses carried out to determine the best CER model for the above database.

Table B2. Regression Analysis Model

Analysis No.	CER
1	Cost = $\beta_o + \beta_1$ (Payload)
2	Cost = $\beta_o + \beta_1$ (Endurance)
3	Cost = $\beta_o + \beta_1$ (MTOW)
4	Cost = $\beta_o + \beta_1$ (Thrust)
5	Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Endurance)
6	Cost = $\beta_o + \beta_1$ (Payload) + β_2 (MTOW)
7	Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Thrust)
8	Cost = $\beta_o + \beta_1$ (Endurance) + β_2 (MTOW)
9	Cost = $\beta_o + \beta_1$ (Endurance) + β_2 (Thrust)
10	Cost = $\beta_o + \beta_1$ (MTOW) + β_2 (Thrust)
11	Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Endurance) + β_3 (MTOW)
12	Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Endurance) + β_3 (Thrust)
13	Cost = $\beta_o + \beta_1$ (Payload) + β_2 (MTOW) + β_3 (Thrust)
14	Cost = $\beta_o + \beta_1$ (Endurance) + β_2 (MTOW) + β_3 (Thrust)
15	Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Endurance) + β_3 (MTOW) + β_4 (Thrust)

C. RESULTS

The results of the regression analyses for all the possible CER are tabulated in table B3 with their respective R-Square value and F-value:

Table B3. R-Square and F-Value Results from the Linear Regression Analysis

Analysis No.	CER	R Square	F-Value
1	Cost = 1.69 + 0.0227 (Payload)	0.667	22.0
2	Cost = 7.33 + 0.142 (Endurance)	0.054	0.628
3	**Cost = 2.27 + 0.00234 (MTOW)**	**0.930**	**133**
4	Cost = 3.74 + 0.00951 (Thrust)	0.556	6.27
5	Cost = 4.36 + 0.0286 (Payload) - 0.224 (Endurance)	0.754	15.4
6	Cost = 2.26 + 9.44E-05 (Payload) + 0.00232 (MTOW)	0.930	59.6
7	Cost = 2.65 + 0.00660 (Payload) + 0.00573 (Thrust)	0.705	4.78
8	Cost = 1.75 + 0.0284 (Endurance) + 0.00229 (MTOW)	0.932	61.5
9	Cost = 1.16 + 0.104 (Endurance) + 0.00789 (Thrust)	0.769	6.65
10	Cost = 2.42 + 0.00283 (MTOW) – 0.00449 (Thrust)	0.831	9.83
11	Cost = 1.72 – 0.00406 (Payload) + 0.0551 (Endurance) + 0.00261 (MTOW)	0.934	37.5
12	Cost = 1.26 + 0.00110 (Payload) + 0.0929 (Endurance) + 0.00744 (Thrust)	0.770	3.36
13	Cost = 2.63 – 0.00605 (Payload) + 0.00451 (MTOW) – 0.00936 (Thrust)	0.858	6.06
14	Cost = 2.21 + 0.0137 (Endurance) + 0.00255 (MTOW) – 0.00333 (Thrust)	0.832	4.95
15	Cost = 2.28 – 0.00632 (Payload) + 0.0236 (Endurance) + 0.00411 (MTOW) – 0.00759 (Thrust)	0.861	3.11

From the results generated, Analysis 3 gives the best CER model, with a high R-square value and F-value, suggesting that the high degree of variability in the model is explained by the parameter MTOW and is significant in the model in the presence of other parameters.

However, this CER is not used in the Zephyr Aircraft AUC calculation because the cost data found in the open source lacks critical information. The sources did not specify for which year the cost was computed and it also did not specify the components that contribute to the cost. Thus, the cost stated in the source could be cost for acquiring the aircraft only, the cost of acquiring the aircraft plus the logistics support etc. Therefore, this computation is not used to predict the Zephyr aircraft AUC.

D. RESULTS SUMMARY OUTPUT

SUMMARY OUTPUT (ANALYSIS 1: Cost = $\beta_o + \beta_1$ (Payload))

Regression Statistics	
Multiple R	0.816391925
R Square	0.666495775
Adjusted R Square	0.636177209
Standard Error	6.39962861
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	900.3228825	900.322882	21.9830903	0.000662245
Residual	11	450.5077098	40.9552463		
Total	12	1350.830592			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.691284475	2.580595078	0.65538545	0.52568885	-3.988566992	7.37113594
Payload (kg)	0.022674343	0.004836045	4.68861284	0.00066224	0.012030279	0.03331840

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*
1	11.66799527	-8.467995273
2	4.774995085	0.725004915
3	8.470912949	-0.470912949
4	6.844544185	1.155455815
5	22.25691333	-9.256913325
6	7.359870156	-0.859870156
7	12.00811041	-2.008110414
8	32.52839058	2.471609421
9	11.8947387	6.6052613
10	2.462212127	-1.562212127
11	1.743435463	-1.678435463
12	2.258143043	-1.758143043
13	11.8947387	15.1052613

SUMMARY OUTPUT (ANALYSIS 2: Cost = $\beta_o + \beta_1$ (Endurance))

Regression Statistics	
Multiple R	0.232348791
R Square	0.053985961
Adjusted R Square	-0.032015315
Standard Error	10.77836513
Observations	13

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	72.92588753	72.9258875	0.6277344	0.444938698
Residual	11	1277.904705	116.173155		
Total	12	1350.830592			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	7.326719511	4.9717475	1.47367088	0.1686024	-3.61602294	18.2694619
Endurance (hrs)	0.142694495	0.180102296	0.79229692	0.4449387	-0.253707985	0.53909697

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*
1	13.0344993	-9.83449929
2	7.89749749	-2.39749749
3	11.60755435	-3.607554352
4	12.46372132	-4.46372132
5	14.31874975	-1.318749752
6	13.0344993	-6.534499299
7	9.039053447	0.960946553
8	12.46372132	22.53627868
9	10.75138738	7.748612616
10	8.040191984	-7.140191984
11	7.433740382	-7.368740382
12	8.182886479	-7.682886479
13	7.89749749	19.10250251

SUMMARY OUTPUT (ANALYSIS 3: Cost = $\beta_o + \beta_1$ (MTOW))

Regression Statistics	
Multiple R	0.964280391
R Square	0.929836672
Adjusted R Square	0.922820339
Standard Error	2.720666919
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	980.9508381	980.9508	132.5246	4.3127E-07
Residual	10	74.02028483	7.402028		
Total	11	1054.971123			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.267299071	0.984284154	2.303500	0.043991	0.07417731	4.4604208
MTOW (kg)	0.002338654	0.00020315	11.51193	4.313E-07	0.00188606	0.0027913

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*
1	4.699498736	1.49949873
2	4.652725665	0.847274335
3	9.90534148	-1.90534148
4	5.775279357	2.224720643
5	13.96056669	-0.960566691
6	4.839817947	1.660182053
7	9.496077113	0.503922887
8	36.48180013	-1.481800127
9	11.85577852	6.644221481
10	2.746723043	-1.846723043
11	2.273613435	-2.208613435
12	2.477777888	-1.977777888

SUMMARY OUTPUT (ANALYSIS 4: Cost = $\beta_o + \beta_1$ (Thrust))

Regression Statistics	
Multiple R	0.74595636
R Square	0.55645089
Adjusted R Square	0.46774107
Standard Error	2.82521791
Observations	7

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	50.0678616	50.0678616	6.2727090	0.05418856
Residual	5	39.9092811	7.98185623		
Total	6	89.9771428			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.73590624	1.51935315	2.45887944	0.0573074	-0.16971538	7.64152786
Thrust (kW)	0.00950760	0.00379615	2.50453768	0.0541885	-0.00025071	0.01926592

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	4.42996138	-1.22996139	-0.47690311
2	6.71178653	-1.21178654	-0.46985602
3	10.4672904	-2.46729042	-0.95666293
4	4.67715911	3.32284088	1.28839258
5	10.4672904	2.53270957	0.98202844
6	4.42996138	2.07003861	0.80263319
7	3.91655073	-3.01655073	-1.16963217

SUMMARY OUTPUT (ANALYSIS 5: Cost = β_o + β_1 (Payload) + β_2 (Endurance))

Regression Statistics	
Multiple R	0.964281403
R Square	0.929838624
Adjusted R Square	0.914247207
Standard Error	2.867794847
Observations	12

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	2	980.9528973	490.476448	59.6378527	6.41862E-06
Residual	9	74.01822558	8.22424728		
Total	11	1054.971123			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.256567826	1.239499107	1.82054816	0.10201451	-0.54737395	5.060509603
Payload (kg)	9.4434E-05	0.005967912	0.01582362	0.98772033	-0.01340592	0.013594788
MTOW (kg)	0.002329972	0.000588981	3.95593730	0.00332466	0.00099760	0.003662339

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*
1	4.721289133	-1.521289133
2	4.645981777	0.854018223
3	9.894490505	-1.894490505
4	5.772987343	2.227012657
5	13.99207694	-0.99207694
6	4.843144969	1.656855031
7	9.501477191	0.498522809
8	36.47248108	-1.472481081
9	11.85194627	6.648053734
10	2.737422739	-1.837422739
11	2.263075947	-2.198075947
12	2.46862611	-1.96862611

SUMMARY OUTPUT (ANALYSIS 6: Cost = $\beta_o + \beta_1$ (Payload) + β_2 (MTOW))

Regression Statistics	
Multiple R	0.964281403
R Square	0.929838624
Adjusted R Square	0.914247207
Standard Error	2.867794847
Observations	12

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	2	980.9528973	490.476448	59.6378527	6.4186E-06
Residual	9	74.01822558	8.22424728		
Total	11	1054.971123			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.256567826	1.239499107	1.82054816	0.10201451	-0.54737395	5.060509603
Payload (kg)	9.4434E-05	0.005967912	0.01582362	0.98772033	-0.01340592	0.013594788
MTOW (kg)	0.002329972	0.000588981	3.95593730	0.00332466	0.00099760	0.003662339

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*
1	4.721289133	-1.521289133
2	4.645981777	0.854018223
3	9.894490505	-1.894490505
4	5.772987343	2.227012657
5	13.99207694	-0.99207694
6	4.843144969	1.656855031
7	9.501477191	0.498522809
8	36.47248108	-1.472481081
9	11.85194627	6.648053734
10	2.737422739	-1.837422739
11	2.263075947	-2.198075947
12	2.46862611	-1.96862611

SUMMARY OUTPUT (ANLYSIS 7: Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Thrust))

Regression Statistics	
Multiple R	0.839541169
R Square	0.704829375
Adjusted R Square	0.557244062
Standard Error	2.576752294
Observations	7

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	2	63.41853332	31.70926666	4.77574198	0.087125698
Residual	4	26.55860953	6.639652383		
Total	6	89.97714286			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.649570292	1.583402564	1.67333965	0.16957510	-1.746660006	7.04580059
Payload (kg)	0.006597486	0.004652642	1.41800867	0.22916904	-0.006320318	0.01951529
Thrust (kW)	0.005731647	0.004367873	1.312228368	0.25967791	-0.006395513	0.01785880

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	5.970874431	-2.770874431	-1.317012216
2	5.340833995	0.159166005	0.075652498
3	8.680224898	-0.680224898	-0.323314724
4	4.716432033	3.283567967	1.56069834
5	12.69149645	0.308503546	0.146633472
6	4.71735207	1.78264793	0.847302597
7	2.982786118	-2.082786118	-0.989959967

SUMMARY OUTPUT: (ANALYSIS: Cost = βo + β1 (Endurance) + β2 (MTOW))

Regression Statistics	
Multiple R	0.965329203
R Square	0.93186047
Adjusted R Square	0.916718352
Standard Error	2.826172057
Observations	12

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	2	983.0858864	491.54294	61.540960	5.62725E-06
Residual	9	71.88523647	7.9872485		
Total	11	1054.971123			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.747615289	1.433789555	1.2188785	0.2538730	-1.495842016	4.99107259
MTOW (kg)	0.002287182	0.000233332	9.8022505	4.224E-06	0.001759348	0.00281501
Endurance (hrs)	0.028435008	0.054998151	0.5170175	0.6176086	-0.095979454	0.15284946

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*
1	5.263685206	-2.063685206
2	4.194281282	1.305718718
3	10.07060296	-2.070602964
4	6.20204904	1.79795096
5	14.57684225	-1.576842246
6	5.400916145	1.099083855
7	9.15851592	0.84148408
8	36.23275285	-1.232752846
9	11.80750297	6.692497031
10	2.358662702	-1.458662702
11	1.775116937	-1.710116937
12	2.124071744	-1.624071744

SUMMARY OUTPUT (ANALYSIS 9: Cost = βo + β1 (Endurance) + β2 (Thrust))

Regression Statistics	
Multiple R	0.876863266
R Square	0.768889188
Adjusted R Square	0.653333782
Standard Error	2.280059789
Observations	7

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	2	69.18245229	34.59122615	6.6538573	0.053412208
Residual	4	20.79469056	5.198672641		
Total	6	89.97714286			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.15905735	1.819191456	0.637127745	0.5586814	-3.891827864	6.20994256
Endurance (hrs)	0.104235145	0.054359807	1.91750394	0.1276378	-0.046691876	0.25516216
Thrust (kW)	0.007888926	0.003177814	2.482501046	0.0680285	-0.000934099	0.01671195

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	5.904354728	-2.70435472	-1.452656899
2	4.045231682	1.454768318	0.781435664
3	9.871471114	-1.87147111	-1.005269537
4	5.692526217	2.307473783	1.239470428
5	11.85193887	1.148061132	0.616686453
6	5.904354728	0.595645272	0.319953668
7	1.830122664	-0.93012266	-0.499619777

SUMMARY OUTPUT (ANALYSIS 10: Cost = $\beta_o + \beta_1$ (MTOW) + β_2 (Thrust))

Regression Statistics	
Multiple R	0.911543265
R Square	0.830911123
Adjusted R Square	0.746366685
Standard Error	1.950264984
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	74.7630088	37.3815044	9.82809914	0.028591048
Residual	4	15.2141340	3.80353350		
Total	6	89.9771428			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.416558899	1.16966610	2.06602456	0.10771427	-0.830954826	5.6640726
MTOW (kg)	0.002827762	0.00110976	2.54807487	0.06343482	-0.000253437	0.0059089
Thrust (kW)	-0.004489341	0.00608618	-0.7376276	0.50167153	-0.021387312	0.0124086

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	5.029709628	-1.82970963	-1.14903744
2	3.895712478	1.60428752	1.00747484
3	8.473576476	-0.47357648	-0.2974008
4	6.213757347	1.78624265	1.12174065
5	13.37691606	-0.37691606	-0.23669912
6	5.199375358	1.30062464	0.81677791
7	2.910952657	-2.01095266	-1.26285606

SUMMARY OUTPUT
(ANALYSIS 11: Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Endurance) + β_3 (MTOW))

Regression Statistics	
Multiple R	0.966270057
R Square	0.933677822
Adjusted R Square	0.908807006
Standard Error	2.957363313
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	985.0031408	328.334380	37.5411004	4.6333E-05
Residual	8	69.9679821	8.74599776		
Total	11	1054.971123			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.720485306	1.501464767	1.14587124	0.28496618	-1.741898653	5.18286926
Payload (kg)	-0.004057438	0.008665961	-0.46820407	0.65213005	-0.024041179	0.01592630
MTOW (kg)	0.002611859	0.000735181	3.55267373	0.00748020	0.000916528	0.00430719
Endurance (hrs)	0.055147749	0.081038595	0.68051215	0.51538835	-0.131727586	0.24202308

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*
1	4.857456231	-1.657456231
2	4.053361271	1.446638729
3	10.69207646	-2.692076459
4	6.701448283	1.298551717
5	13.80192546	-0.801925461
6	5.78508103	0.71491897
7	8.609381252	1.390618748
8	36.39919095	-1.399190947
9	11.92680752	6.573192475
10	2.393702324	-1.493702324
11	1.75956603	-1.69456603
12	2.185003188	-1.685003188

SUMMARY OUTPUT
(ANALYSIS 12: Cost = $\beta_o + \beta_1$ (Payload) + β_2 (Endurance) + β_3 (Thrust))

Regression Statistics	
Multiple R	0.877778722
R Square	0.770495484
Adjusted R Square	0.540990968
Standard Error	2.623620947
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	69.32698223	23.10899408	3.3572127	0.173221889
Residual	3	20.65016062	6.883386874		
Total	6	89.97714286			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.258552719	2.20304486	0.571278752	0.6078040	-5.752519257	8.26962469
Payload (kg)	0.0011002	0.007592656	0.144903149	0.8939748	-0.02306302	0.02526341
Endurance (hrs)	0.092882546	0.10025325	0.926479155	0.4225332	-0.226168039	0.41193313
Thrust (kW)	0.007435541	0.004812585	1.545020212	0.2200511	-0.007880252	0.02275133

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	6.000736963	-2.80073696	-1.509684622
2	4.107034437	1.392965563	0.750851907
3	9.638351942	-1.63835194	-0.883122823
4	5.588488356	2.411511644	1.299880029
5	12.07204177	0.927958235	0.500198446
6	5.791699013	0.708300987	0.381796335
7	1.901647523	-1.00164752	-0.539919272

SUMMARY OUTPUT
(ANALYSIS 13: Cost = $\beta_o + \beta_1$ (Payload) + β_2 (MTOW) + β_3 (Thrust))

Regression Statistics	
Multiple R	0.926454182
R Square	0.858317351
Adjusted R Square	0.716634702
Standard Error	2.061407281
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	77.2289429	25.7429809	6.0580272	0.086585144
Residual	3	12.7481999	4.24939997		
Total	6	89.97714286			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.626918697	1.26678771	2.07368501	0.1297837	-1.40456518	6.6584025
Payload (kg)	-0.006049838	0.00794176	-0.76177537	0.5016066	-0.031324064	0.0192243
MTOW (kg)	0.004511972	0.00250280	1.80276647	0.1692106	-0.003453069	0.0124770
Thrust (kW)	-0.009363376	0.00907312	-1.03199028	0.3779847	-0.038238108	0.0195113

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	3.973914666	-0.77391466	-0.53093856
2	3.475615537	2.02438446	1.38881436
3	8.924847712	-0.92484771	-0.63448508
4	7.092939512	0.90706048	0.62228229
5	13.07030608	-0.07030608	-0.04823297
6	5.394102142	1.10589785	0.75869323
7	3.16827435	-2.26827435	-1.55613322

SUMMARY OUTPUT
(ANALYSIS 14: Cost = $\beta_o + \beta_1$ (Endurance) + β_2 (MTOW) + β_3 (Thrust))

Regression Statistics	
Multiple R	0.912114789
R Square	0.831953388
Adjusted R Square	0.663906775
Standard Error	2.245020717
Observations	7

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	3	74.8567888	24.9522629	4.9507298	0.110862774
Residual	3	15.1203540	5.04011801		
Total	6	89.9771428			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.206554254	2.04527083	1.07885675	0.3596630	-4.302410349	8.71551885
Endurance (hrs)	0.01373554	0.10069572	0.13640638	0.9001392	-0.306723205	0.33419428
MTOW (kg)	0.002550079	0.00240334	1.06105327	0.3665193	-0.005098443	0.01019860
Thrust (kW)	-0.003328157	0.01102498	-0.3018741	0.7824651	-0.038414576	0.03175826

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	5.165102533	-1.96510253	-1.23788375
2	3.820863818	1.67913618	1.05774398
3	8.590843207	-0.59084320	-0.37219188
4	6.196664613	1.80333538	1.13598121
5	13.2736554	-0.27365539	-0.17238468
6	5.31810727	1.18189273	0.74451372
7	2.734763161	-1.83476316	-1.15577862

SUMMARY OUTPUT
(ANALYSIS 15: Cost = β_o + β_1 (Payload) + β_2 (Endurance) + β_3 (MTOW) + β_4 (Thrust))

Regression Statistics	
Multiple R	0.928077321
R Square	0.861327514
Adjusted R Square	0.583982543
Standard Error	2.497734378
Observations	7

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	4	77.49978881	19.3749472	3.1056179	0.258114913
Residual	2	12.47735405	6.23867702		
Total	6	89.97714286			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.2761945	2.278013414	0.99920153	0.4229571	-7.525306132	12.0776951
Payload (kg)	-0.006319792	0.00970958	-0.6508821	0.5819121	-0.048096743	0.03545715
Endurance (hrs)	0.023553368	0.113041563	0.20836024	0.8542405	-0.462825221	0.50993195
MTOW (kg)	0.00411096	0.003591732	1.14456209	0.3708939	-0.011343015	0.01956493
Thrust (kW)	-0.007589694	0.013904059	-0.54586176	0.6399100	-0.06741403	0.05223464

RESIDUAL OUTPUT

Observation	*Predicted Cost USD (million)*	*Residuals*	*Standard Residuals*
1	4.15897169	-0.95897169	-0.66499773
2	3.328521432	2.171478568	1.50580912
3	9.146070336	-1.146070336	-0.79474105
4	7.102859949	0.897140051	0.62212065
5	12.87955577	0.120444233	0.08352190
6	5.606389764	0.893610236	0.61967291
7	2.877631063	-1.977631063	-1.37138581

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LIST OF REFERENCES

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